

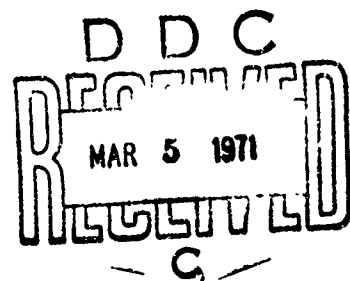
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PAPER P-702

A STUDY OF NATIONAL TRAVEL REQUIREMENTS FOR STRATEGIC EVACUATION

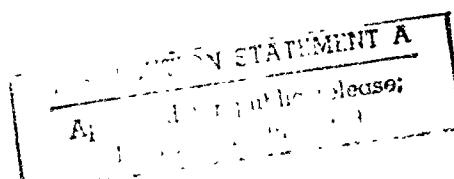
Leo A. Schmidt

March 1970



INSTITUTE FOR DEFENSE ANALYSES
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Leo A. Schmidt

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for

Office of Civil Defense
Office of the Secretary of the Army
Washington, D.C. 20310

This Paper has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.



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FOREWORD

The work described in this Paper concerns the question of strategic evacuation. Since the implications of evacuation on civil defense operations would be so great if even partial evacuation were implemented, information about its feasibility could have direct effects upon civil defense planning. Accordingly, this study was undertaken in hopes of elucidating at least some aspects of these problems.

This work was conducted under the general guidance of Mr. Neal FitzSimons, Staff Director of the Systems Evaluation Division of the Office of Civil Defense, under OCD Contract DAHC 20-70-C-0287, Task Order 4114B, Evaluation of Total Civil Defense Systems. The work was under the supervision of Dr. Abner Sachs of the Institute for Defense Analyses.

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SUMMARY

The strategic evacuation of cities as a possible civil defense measure is a controversial issue because of difficulties in adequately assessing its requirements and effectiveness. In this paper, calculations are made of the travel requirements from large urban centers to rural reception areas under the assumption that a reception area can house four times its normal population. The New York and Los Angeles areas required large travel distances; however, for the remainder of the country, average travel distances of about 60 miles are indicated.

The computer results for evacuating the Detroit area were studied in more detail as an example of the nationwide calculations. The pattern of reception centers appeared consistent with the regional areas defined by the Office of Business Economics of the Department of Commerce. The size of these regional areas appeared appropriate as a basis for evacuation planning as well as for postattack assistance to major centers. The most critical deficiency found, besides a lack of adequate regional planning, was a lack of fallout shelters in rural areas to house the evacuated population. Unless a large number of rural shelter spaces could be located and added to current inventories, an expedient shelter construction program would appear to be a necessary prelude to any nationwide evacuation.

I

INTRODUCTION

One of the most controversial civil defense measures is the strategic evacuation of cities. Among the issues raised about the feasibility of strategic evacuation are the following:

- (1) The availability of adequate strategic warning so that evacuation procedures can be initiated in sufficient time.
- (2) The immense logistical problem of meeting even subsistence needs of a displaced urban population.
- (3) The resistance on the part of the populace to evacuation.
- (4) The unavailability of fallout protection in proposed reception centers.
- (5) The difficulties of imagining the implementation of such large-scale measures associated with a strategic evacuation. It is easier to conceive of large-scale post-attack operations because they would follow the immense disruption of a nuclear war.
- (6) The lack of adequate planning for evacuation.

The primary reason for considering strategic evacuation is the possibility that it might be highly effective. As an extreme viewpoint, one can imagine an evacuation so complete and effective that the casualties from a nuclear attack might be no worse than those undergone in World War II. Such a possibility, however remote, raises several issues:

- (1) If evacuation can be made effective, it might be more efficient than any other civil defense system by producing far more expected survivors per dollar.
- (2) If the casualties resulting from a nuclear attack can be reduced to numbers no higher than others within recent historical experience, then the publicized horrors of nuclear warfare, which are the cornerstone of deterrence, are reduced in scale. The entire basis of our strategic position would have to be reconsidered.

(3) If evacuation is effective and is accomplished in one country but not another in some crises, then nuclear blackmail becomes more of a possibility.

(4) Furthermore, the importance of measures to prevent evacuation by the other side becomes a matter of prime national policy. This may imply a need for a hair trigger on our nuclear weaponry and a correspondingly higher likelihood of its use. Thus, evacuation plans might be an important part of strategic arms limitation talks.

During the 1950's many civil defense plans were based upon evacuation, so that the approach is certainly not new. Currently, many local civil defense personnel seem implicitly, if not explicitly, to place credence in evacuation possibilities. Several studies are available concerning questions of housing, food, and similar items supporting an evacuation. There seems to be a dearth of information, however, about the geographical relationships between major urban centers and the supporting rural areas. While the availability of reception centers around Clarksburg, West Virginia may not be a problem,¹ the availability of reception centers in the Washington-New York-Boston metropolitan corridors may be one. The delineation of the geographical requirement for evacuation should underlie detailed planning or analysis. The political subdivision of local civil defense activities has tended to minimize such planning, while on a national basis there have been only a minimal number of evacuation studies recently.

This Paper addresses the question of evacuation through a calculation which determines travel distance necessary to simultaneously evacuate to reception areas all major population centers in the United States, thus developing a geographically feasible national evacuation plan. Some features of this plan are discussed; however, not all of the points raised at the beginning of this section are addressed directly. Since a data base including travel routes was not available, distances were computed simply from differences in latitude and longitude. The distances used are lower bounds of

1. People in the Washington area seem to consider the hills of West Virginia as the ideal evacuation refuge.

actual distances and do not represent actual travel routes. The results obtained in particular areas are thus sometimes rather unrealistic, and the computer calculations should be studied to determine the usefulness of the general policy rather than to obtain specific evacuation plans. The calculations performed may be of interest for other purposes besides evacuation. For example, the geographic relations obtained may be used in assessing postattack operations defined on a regional basis, as illustrated in Section 4.

The next section of this report describes the United States population data base used for the evacuation study. In Section 3 the methodology used to disperse the population is presented, followed by a description of the computer results. In Section 4 the results for one area are analyzed in detail to indicate how actual evacuation strategies could be developed from the general procedures of the study.

II

POPULATION LOCATION

Many damage assessment studies use population aggregations by the 212 Standard Metropolitan Statistical Areas (SMSAs) as target cities. Such descriptions of population are inadequate for evacuation studies that attempt to describe the reception potential of rural areas or small urban areas in terms of the indigenous population. Therefore, a new description of population is needed that includes small urban and rural areas.

The population description used in this paper was obtained from an Office of Civil Defense (OCD) data tape which gives estimates of 1975 population based on extrapolation of 1960 census data. The basic division of population was 1960 census tracts. Many of these tracts had been combined into an OCD-OEP¹ National Location Code--the Region, State, Area, County (RSAC) Code--which describes the population by about 44,000 "Standard Location Areas" (SLAs). The OCD data tape has for each SLA a code identification, the latitude and longitude of the center of population, the estimated 1975 population, and an urban/rural designation. The identification code specifies the state, county, and the Standard Metropolitan Statistical Area (SMSA) of each SLA. SLAs representing towns of 2,500 or more, or parts of larger cities, have an urban designation; the others have a rural one. There are approximately 27,000 urban SLAs and 17,000 rural SLAs in the United States. The population of each SLA averages about 5,000 people. An attempt was made in the original division to keep the population in each SLA between limits of 2,000 and 10,000 people.

1. Office of Emergency Preparedness.

In the data base developed for this study, clusters of urban SLAs were aggregated into entities and called cities. Each cluster included all "contiguous" SLAs, where the criterion for contiguity was a separation of no more than about three miles from its nearest neighbor.² These SLA clusters were considered as coherent targets; any urban SLAs outside of the clusters were therefore considered as independent targets for nuclear weapons.

In order to obtain these clusters all urban SLAs were plotted upon overlays to regional maps. Those SLAs which were contiguous were then observed, the identification codes determined, and computer input prepared which would perform the appropriate aggregation. Several large clusters were divided at the most appropriate appearing dividing lines, even though tracts might be considered contiguous, to preserve what appeared to be natural sized target areas. A certain degree of arbitrariness is appropriate here, unless an extremely complicated set of rules is used to define target clusters.³

This process produced a total of 3,146 cities. Figure 1 shows the result of ranking cities by population and plotting population as a function of city rank. It is interesting to note the break in slope at about 20 cities. The break in slope at 2,000 cities may be a real effect or may be an accident of the way small cities are defined as urban. The total population in these cities is 164 million people,

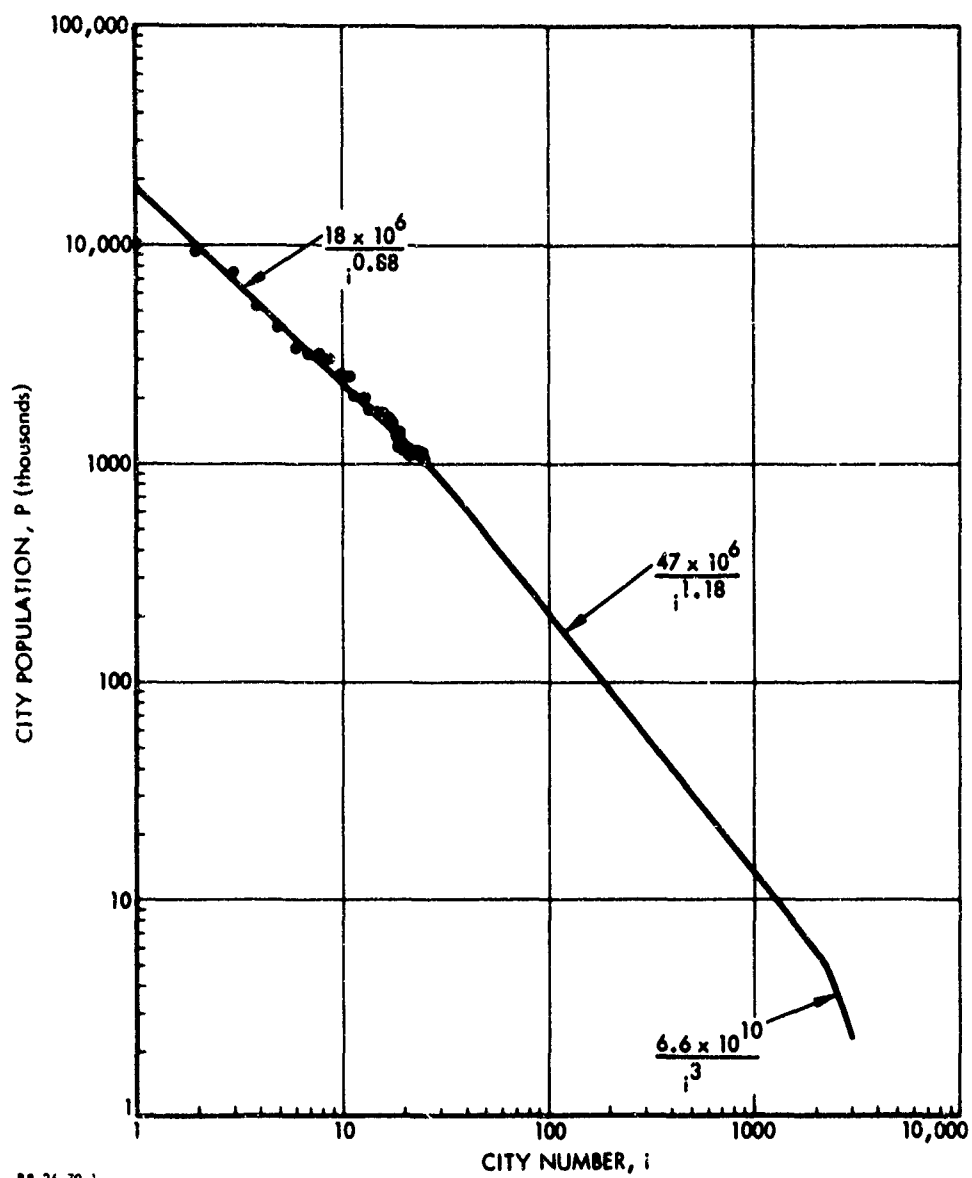
2. This criterion was adopted to include in a single cluster SLAs which might be separated by a river or small rural area from the remainder of the cluster.

3. A number of sources of errors could occur in this process. The original aggregation was rapidly done since the desirability of the entire calculation was still in question. Furthermore, a number of errors existed in the basic definitions. A recent and much more careful redefinition of the target system has produced a new target system which differs in some details but which confirms the general nature of the calculation here. See Dietrich L. Petersen and Leo A. Schmidt, Jr., Population and Spatial Structures in the United States, IDA Research Paper I-706, (September 1970 - to be published).

with 108 million in cities of over 250,000, 36 million in cities between 25,000 and 250,000, and about 20 million in cities under 25,000.

In the addition to the cities, the rural population in the 3,106 counties was also used as population elements. The total rural population is 59 million people. Of the 3,106 counties, 1,031 have no urban SLAs at all. These rural counties have a population of 10 million; 1,409 counties with a total population of 38 million have only a single city, and this city has only one SLA.

One way of illustrating the distribution of population in the country is to divide the total urban or rural population in a state by the total state area. This is shown in Figure 2 which presents for each state: (1) the total urban population in the state divided by the total state area, and (2) the total rural population for the state divided by the total state area. A high urban population value indicates that the area of the state is relatively small compared to the population to be evacuated and that redistribution of urban population may be a problem. Where the urban population value is much higher than the rural population value, a relative scarcity of reception centers may occur. Thus Figure 2 indicates where problems in relocating population might be expected. The high rural population values in Connecticut, Maryland, and New Jersey may be misleading. They are due in part to the forecasted growth of new suburban areas by 1975 which still maintain the 1960 rural census classification.



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FIGURE 1. City Population as a Function of City Number for Cities Ranked by Size

III

NATIONWIDE CALCULATIONS

Several steps were involved in the calculation of the travel distances required to simultaneously evacuate all major urban centers into reception areas. The basic procedure in the nationwide calculations is the assignment of population from large cities to reception areas. This assignment is made by limiting the population evacuated to any area to some multiple of the indigenous population and then attempting to minimize average travel distances from cities to reception areas.¹ In order to describe this procedure more precisely, the population is divided into two classes; large cities designated by the subscript i , and small cities/rural areas designated by the subscript j . The total number of large cities will be called M , and the total number of small cities and rural areas, N . Then call

- d_{ij} - the distance from the i th to the j th center,
- x_{ij} - the population assigned from the i th to the j th center,
- P_i - the population of the i th large city,
- P_j - the population of the j th city/rural area, and
- L_j - the limit of the population which can be assigned to the j th small city/rural area.

For rural reception centers the value of L_j is taken as some multiple, α_r , of the indigenous population. For small urban reception centers L_j is taken either as the minimum of some multiple of the indigenous

1. An alternative procedure might be to limit the maximum travel distance to some value and allocate population to minimize the density of the evacuated population. A real evacuation plan may include elements both of such a procedure and the one discussed in this paper.

population α_u , or at a value where the maximum total population is P_L , whichever is smaller. Thus for L_j we have

$$L_j = \begin{cases} \min(\alpha_u P_j, P_L - P_j) & \text{for small urban areas} \\ \alpha_r P_j & \text{for rural areas.} \end{cases}$$

The problem can now be stated precisely:

$$\text{Minimize } \sum_{i,j} x_{ij} d_{ij}$$

subject to the following constraints:

$$\sum_{j=1}^N x_{ij} = P_i \quad (i=1,2,3,\dots,M).$$

$$\sum_{i=1}^M x_{ij} \leq L_j \quad (j=1,2,3,\dots,N).$$

$$x_{ij} \geq 0.$$

The first set of constraints imposes the requirement that the total population from each large city is evacuated; the second set of constraints limits the population accepted in each reception center to the limit previously calculated. This is a special case of the linear programming problem called the transportation problem. In the usual statement, the second set of constraints are equalities. This can be achieved by introducing the slack variable y_j (i.e., the difference between population assigned and the assignment limit) so that

$$\sum_{i=1}^M x_{ij} + y_j = L_j \quad (j = 1,2,3,\dots,N).$$

In the calculation that follows, two cases will be considered.

In the first, all cities over 250,000 will be evacuated; in the second, only cities of over 50,000 will be evacuated. The values of α_r and α_u are 4 and $P_L = 25,000$. Cities between 25,000 and 250,000 were excluded in the first case, and cities between 25,000 and 50,000 were excluded in the second case. Table 1 indicates some properties of these two cases.

Table 1
SOME PROPERTIES OF THE TWO CASES CONSIDERED
IN THE TRANSPORTATION PROBLEM

Minimum Size City Evacuated	250,000	50,000
Number of Cities Evacuated	89	451
Population of Cities Evacuated (10^6)	108	134
Number of Cities Not Considered	533	270
Pre-evacuation Population in Cities Not Considered (10^6)	36	9
Number of Small Cities (under 25,000)	2513	
Pre-evacuation Population in Small Cities (10^6)	20	
Number of Counties in U.S.	3106	
Rural Population in Counties (10^6)	59	
Number of Counties and Small Cities	5619	
Pre-evacuation Rural Population in Counties + Population in Small Cities (10^6)	79	
Reception Potential (10^6)	260	

When the values of α_u and $\alpha_r = 4$ were selected, the total reception potential was about twice the population to be evacuated. The resulting evacuation patterns using these values appeared reasonable. While some additional calculations with different values would be desirable, the regional variations in travel requirements are large enough to indicate that an algorithm that takes local conditions into account would be desirable.

The methods of solving the transportation problem show that of the M times N variables only M plus N can have non-zero values. Thus, since here M is much less than N , the number of non-zero variables is about the same as the number of reception centers. This indicates that most of the time a reception center will receive people from only one city. The number of iterations required to solve the transportation problem is usually about M plus N . Since M plus N is a value over 5,000, a large number of iterations is needed for conventional methods of solution. Moreover, the number of calculations needed per iteration is of the order M times N which is about 800,000 calculations for the 250,000 size city case and 2,000,000 for the 50,000 size city case. The number of calculations needed then becomes very large if an exact solution is desired.

The computer program actually developed, called SCATTER 4, obtained only approximate solutions to this problem, but it did so in just a few iterations. The basic method consisted of allocating, at each iteration, each unfilled reception center to some city requiring evacuation. The reception center was allocated to the "nearest" large city, where the actual distance² was divided by the square root of the population in the large city at the start of the iteration to determine a weighted distance used in the allocation routine. This weighting factor permits large cities to obtain more reception centers than small cities. Following this allocation, the remaining population in the large cities was dispersed to the reception centers, filling the nearest first, until either all the population in the large city was evacuated or all the reception centers allocated to the large city on this iteration were filled. Statistics concerning the evacuation status of each city and the entire country were then written. If there were some cities

2. In order to compute distances, latitudes and longitudes were converted to a rectangular grid centered at latitude 40° N, longitude 90° W. Distance between two points was then computed as the square root of the sum of the squares of the differences in the rectangular distance. The loss in accuracy by not using the appropriate spherical calculation was always less than 10 percent and usually much less. This approximation considerably decreased calculation time.

not completely evacuated, the above process was repeated in another iteration. Three iterations sufficed to evacuate the entire country for the 250,000 city case, and six iterations evacuated all but 180,000 people for the 50,000 city case.

For each reception center, it was necessary to store latitude and longitude, the original population, the new population, and an assignment list. Since there are about 6,000 reception centers, this information alone consists of 30,000 items. Since the computer used was a CDC 1604 with a storage of 32,000 words, it was necessary to pack the data to avoid using external storage extensively. These constraints influenced the specific techniques adopted, especially since only approximate solutions were desired.

Two specific problems arising from the algorithm used should be mentioned. The first is that once an allocation of reception centers to a city was made in an iteration, it could not be released in a subsequent iteration, even if closer reception centers became available. As an example, this could occur if a neighboring city had claimed on a prior iteration more spaces than were necessary to receive its population. When these spaces became available to the original city, if it had already completely evacuated its population, it could not improve its original allocation. Several instances where this phenomenon occurred were observed. Thus, occasionally the allocation for a city was suboptimal. The net effect, however, changed the average nationwide travel distance by no more than a few percent.

The second problem is due to a limit of 650 reception centers, imposed by computer storage, which could be allocated in any size iteration. When this limit was exceeded, only the first 650 reception centers on the list, ordered by (RSAC) identification code, were chosen. This occurred once, on the second iteration for the 250,000 city case for Los Angeles, when about 1,700,000 people were misallocated. Fortunately, supplementary data allowed us to make a corrected reallocation by hand. This correction decreased the average travel distance for Los Angeles from 534 to 420 miles. The 420 mile value

is correct to about 5 percent of 420 miles. The correction also decreased the nationwide average three miles from 87 to 84 miles. However, for Los Angeles some of the travel distances for the corrected situation were still over 1,000 miles, so any error in the corrections seems to be, at best, of mathematical interest.

Further efforts in programming could correct those two problems. At present, it is estimated that the average travel distance is no more than 10 percent higher than would be obtained from a true optimum. Considering the nature of the calculation, this certainly seems adequate. Of more importance, it appears that the allocation patterns are quite stable and that a true mathematically optimum allocation would not change the basic patterns. Therefore, it does not seem appropriate to extend the calculation in the direction of more mathematical precision.

Table 2 shows the results from the calculations for the 50,000 city case and the 250,000 city case. In the 250,000 city case, the first iteration allocates everyone except for four principal areas. When smaller cities are located near a very large city, the large city can sometimes so dominate the calculation that it is necessary for the large city population to be completely evacuated before the smaller city can be assigned a reception center. This required three iterations to evacuate everybody in the 250,000 city case. The travel distances needed to evacuate Los Angeles were very large. Because of this, an additional artificial iteration is shown in the table. Iteration 3A shows the average travel distance which would occur if it were only necessary to evacuate 28 percent of the population of Los Angeles. This would then give a maximum travel distance for Los Angeles of 200 miles. The spectacular reduction in average travel distance is due to the relative dearth of population in reception centers near Los Angeles. Iteration 3A, however, produces travel distances of over 200 miles for the additional 72 percent of the population of Los Angeles.

In the 50,000 city size case the average travel distance is somewhat higher than for the 250,000 city size case. Six iterations were needed in the 50,000 city size case to allocate the entire population except for a residual unallocated population of 181,000 people.

Table 2

NATIONWIDE COMPUTER ASSIGNMENT RESULTS

Maximum City Size	Iteration Number	Percent Population Assigned	Average Travel Dist. (n. mi.)	Number Unassigned (10 ⁶)	Remarks
250,000	1	81	40	20.0	Unassigned Popn: N.Y. area 11.1, L.A. area 7.8, Mpls. 1.4, Detroit 1.0, Misc. 0.1
	2	97	84	3.1	All unassigned popn. in N.Y. area
	3	100	88	0	
	3A	93	57	7.2	Only evacuation 28% of L.A. Popn.
	1	67	31	44.3	
	2	89	94	15.0	
	3	96	115	5.6	
	4	98	119	2.2	
	5	99	121	1.0	
	6	99	122	0.2	
50,000	6A	87	68	17.8	Only evacuation 10% of L.A., 9% of N.Y., and 15% of San Diego

This residual is located in three small cities near Los Angeles-- Vista, Ventura, and Del-Mar Solano, and a small city near New York, i.e., Meriden, Connecticut. Iteration 6A indicates that by only partially evacuating the Los Angeles and New York areas, a large reduction in travel distance is again possible.

For each city the number of evacuees located in rings of 20 mile width around the city was calculated. For each ring these populations were summed over the entire country. Figures 3 and 4 show the percent of the evacuated population as a function of distance from the city for the 250,000 and 50,000 calculations. The point shown at 400 miles is really for distances of 410 miles. As can be seen, the curve for the 50,000 case is considerably lower in the 50-to 100-mile region than for the 250,000 case, but this curve has a much higher tail. The higher values at low distances in the 50,000 case occur primarily because of the large number of small cities that have reception centers nearby. If such close reception centers are not available, then there is a higher chance of having to travel quite long distances before finding any reception centers. The values plotted at 410 miles indicate cases where travel to extreme distances are needed to find any reception center at all. For the 50,000 city size case, the average travel distance in this band, at the sixth iteration, is 656 miles. If the population having to travel over 400 miles is removed from the calculation, the average travel distance is decreased to 71 miles, about the same value as when evacuating only a part of the Los Angeles and New York areas. Of the 11.8 million people having to travel over 400 miles, 10.3 million are from Los Angeles, San Diego, and New York.

In order to describe the distribution of maximum travel distances for evacuating cities of 50,000 people or more, it is desirable to aggregate the cities into various size groups as in Table 3, because the distribution changes with city size. The table illustrates the general decrease in distance necessary to travel as the city size decreases.

A striking feature of Table 3 is that 65 percent of all the cities require no more than the innermost band to receive their evacuees. This is described in more detail in Table 4 where the number of different

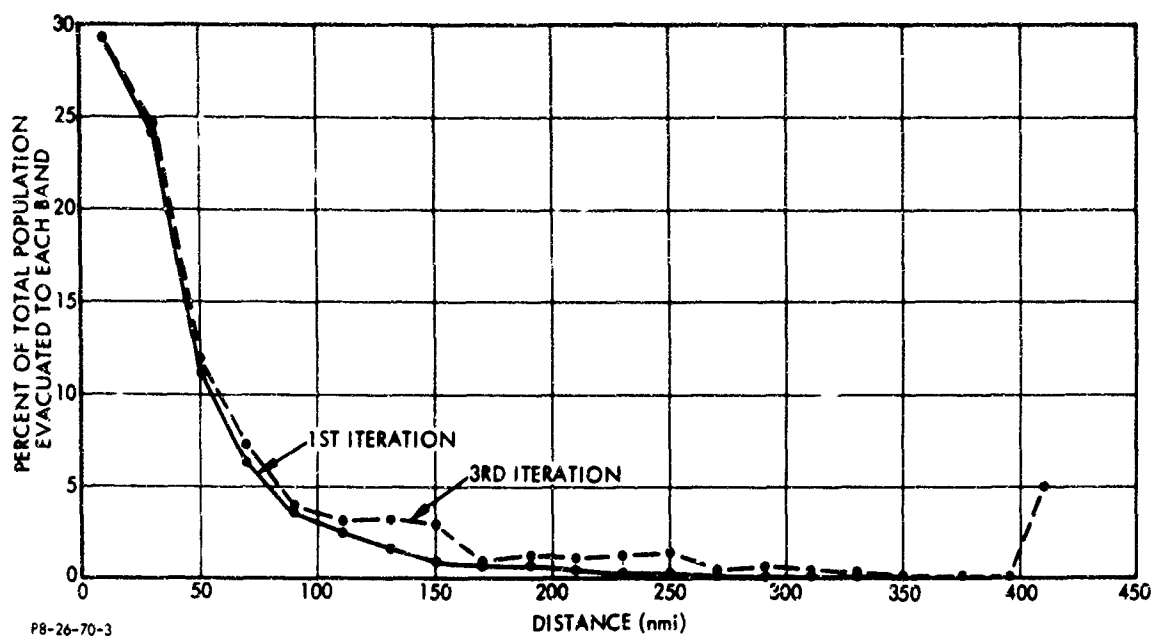


FIGURE 3. Frequency Distribution of Evacuation Distances for the 250,000 City Calculation

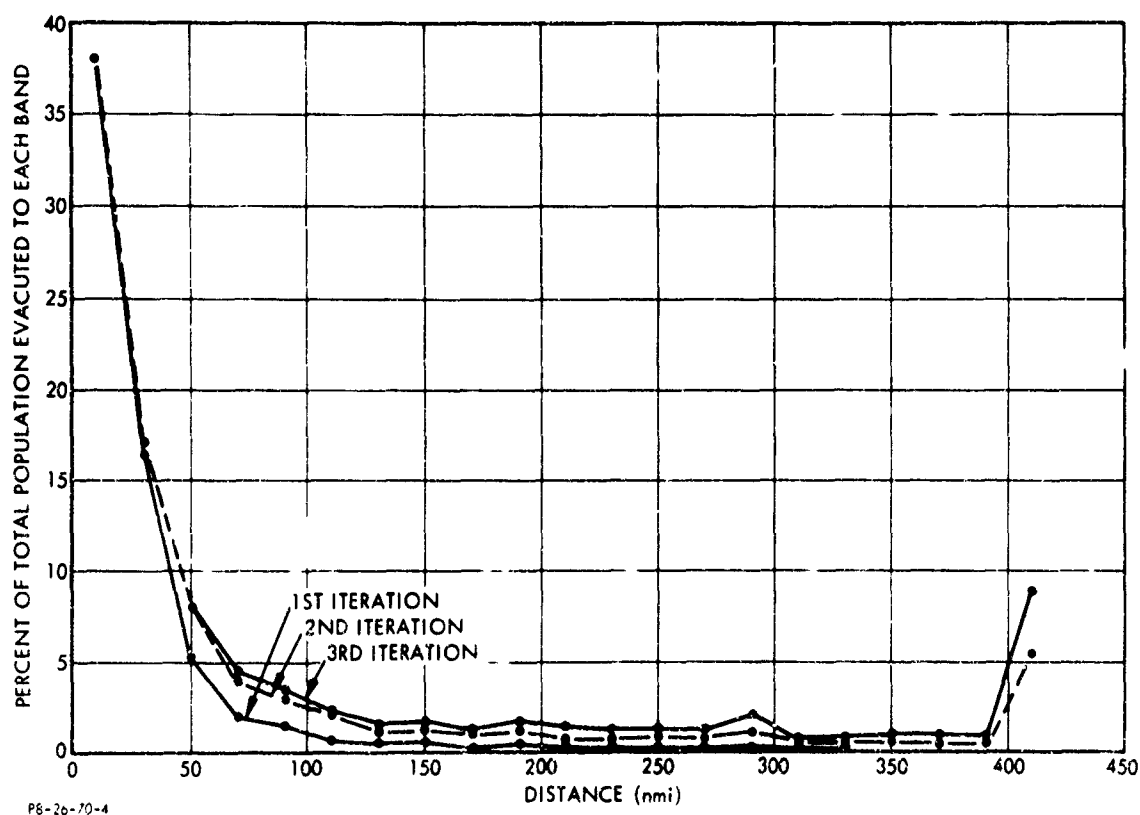


FIGURE 4. Frequency Distribution of Evacuation Distances for the 50,000 City Calculation

Table 3

DISTRIBUTION OF NUMBER OF CITIES EVACUATING TO VARIOUS MAXIMUM DISTANCE RINGS
(Values in Parentheses are Cumulative Percentages Evacuating to These Distances)

Typical City in Group	Population (10 ³)	Number of Cities in Ring	Cumulative Number of Cities	Distance Bands (mi.)																Not Evacuated
				0	20	40	60	80	100	120	140	160	180	200	240	280	320	360	400	
Los Angeles	10,000	1	1																1(100)	
New York	9,344	1	2																1(100)	
Chicago	7,368	1	3																	
San Francisco	5,377	1	4																	
Philadelphia	4,226	1	5							1(100)										
Newark	3,420	1	6																	
Detroit	3,346	1	7																	
Long Island	3,177	1	8																	
Boston	2,998	1	9																	
Miami	2,599	1	10																	
St. Louis	2556-1676	5	15		1(20)	4(80)														
Kansas City	1676-1000	12	27	1(8)	1(16)	4(50)	2(67)	1(75)			2(92)									1(100)
Indianapolis	1000-500	24	51	4(17)	11(65)	4(82)	1(88)	1(81)	1(89)			1(96)								1(100)
Youngstown	500-250	38	89	17(45)	12(76)	1(79)	1(82)				2(88)	3(96)	2(100)							
Charlestown	250-150	50	139	39(78)	5(89)	2(92)					1(94)		1(96)				1(98)			1(100)
Wheeling	150-100	21	190	36(69)	5(79)	4(88)	1(90)	2(94)			2(97)	1(100)								
Battle Creek	100-75	45	235	35(78)	4(87)			1(89)			1(91)	1(93)								3(100)
Lancaster	75-50	116	351	94(82)	7(88)	2(90)	2(92)	1(93)	2(94)		8(91)	7(93)	3(94)	1(95)		1(96)		2(97)		4(100)
Total				224(65)	46(78)	21(84)	7(86)	6(88)	4(89)											4(100)

reception centers in the innermost band receiving evacuees is given for those cities which only require the innermost band. Here it seems that a large percentage of the smallest cities require only one location. In most cases this location is the center of gravity for the rural population of the county in which these cities are located. Despite the large number of cities requiring only this first reception center in the distance band, it should be noted that only 38 percent of the total evacuated population is actually located in this band.

Figures 5 through 8 give a continuous representation of the percentage of population of large cities evacuated at various 20-mile intervals for the 250,000 people city case, and Figure 9 through 12 for the 50,000 people city case. The population is listed for each city, and an arrow on each frequency curve indicates the average travel distance. Note that Figures 5 through 12 present percentages of the city total. The absolute number of people being dispersed to various rings changes drastically between larger and smaller cities. The area in each ring varies as the square of the distance, so that the figures do not represent the population density in each ring. Figures 5, 6, 9, and 10 show the twenty largest cities for each case, indicated by city number. Figures 7, 8, 11, and 12 show cities where the evacuation patterns are more than 10 percent different in any distance between the two cases. These city patterns are reasonably representative, except that no cities are shown for the 50,000 city size case where all the population is in the innermost ring and where all the patterns are the same.

These figures illustrate how the evacuation patterns change with city size, as well as how the two cases differ. The evacuation pattern appears to change radically after the first ten cities, with much smaller travel distances needed. By considering the geographic relations between the cities, many features of the pattern become evident. Thus, for example, the lack of reception centers for Newark at intermediate distances is due to the larger drawing patterns of New York City (see Figure 9). The Newark evacuation is either to very short distances, where the proximity of reception centers overwhelms the differences in size between Newark and New York, or to

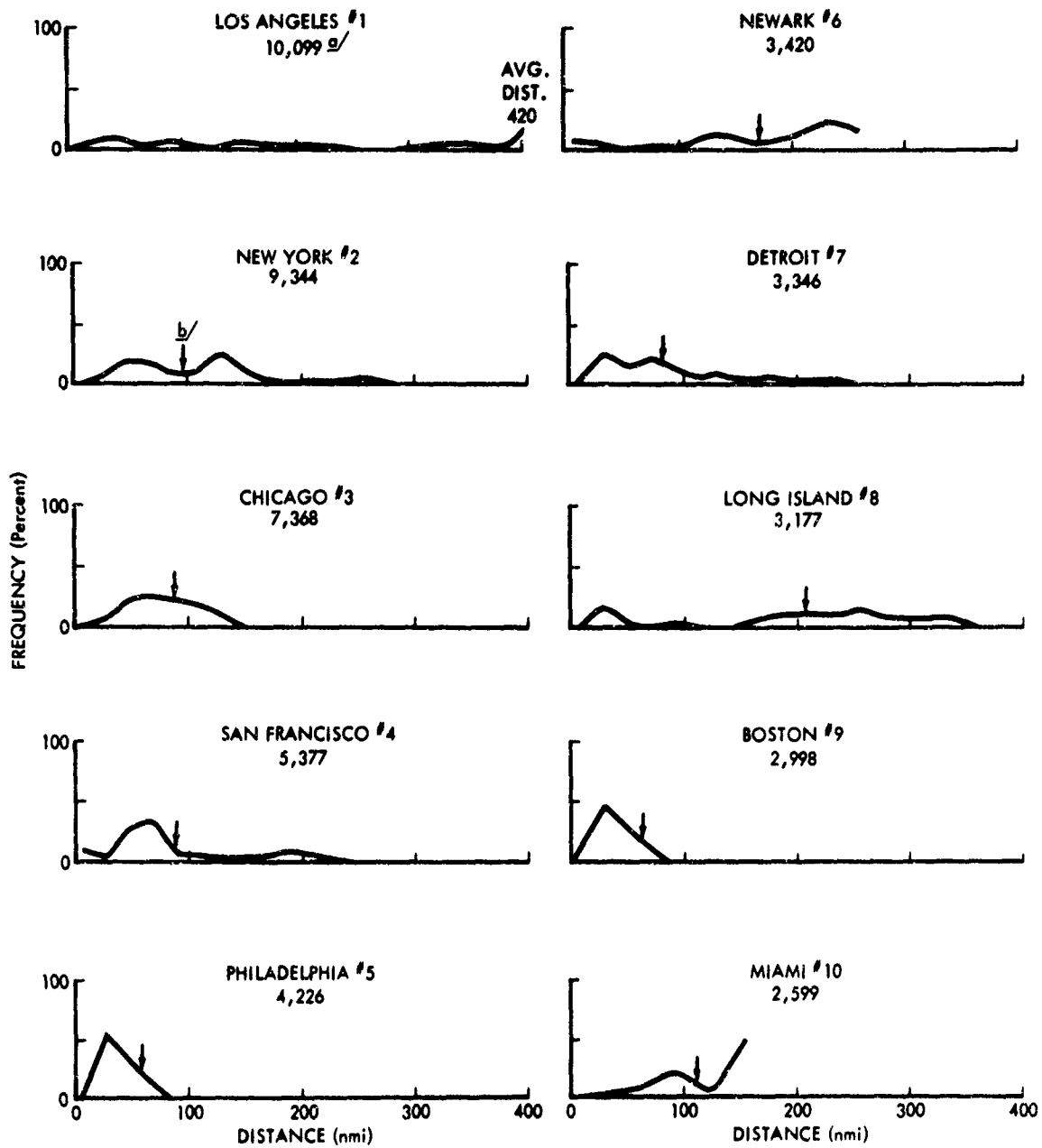
long distances where New York requirements are not as strong. The capability of smaller cities to attract reception centers close to them is illustrated in the differences in the two cases. In the 50,000 people city size case, larger cities have to go much longer distances to find reception centers unoccupied, because cities in the 50,000 to 250,000 people range claimed many which would otherwise be available.

The patterns obtained depend rather strongly on the algorithm to allocate people to reception centers. If the algorithm were changed, this distribution pattern might change in detail. For example, larger cities might be more capable of drawing reception centers at the expense of small ones. However, the nationwide average travel distances would probably be changed only by a small amount.

Table 4

NUMBER OF DIFFERENT RECEPTION CENTERS FOR THOSE
CITIES EVACUATING ONLY TO INNERMOST RING (0-20 MILES)

Typical City in Group	Population (10 ³)	Number of Cities In Group	Number of Cities in Group Evacuating Only to Innermost Ring	Number of Reception Centers Utilized in Evacuation		
				1 Reception Center	2 Reception Centers	3 or More Reception Centers
Kansas City	1676-1000	12	1	1		
Indianapolis	1000-500	24	4	0	1	3
Youngstown	500-250	38	17	4	6	7
Charlestown	250-150	50	39	13	7	19
Wheeling	150-100	52	36	20	9	7
Battle Creek	100-75	45	35	22	7	6
Lancaster	75-50	115	94	75	10	9
Total			226	135	40	51



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^{a/} POPULATION IN 1000s
^{b/} AVERAGE DISTANCE

FIGURE 5. Distribution of Distance Traveled by Evacuees for Target 10 Cities in the 250,000 City Run

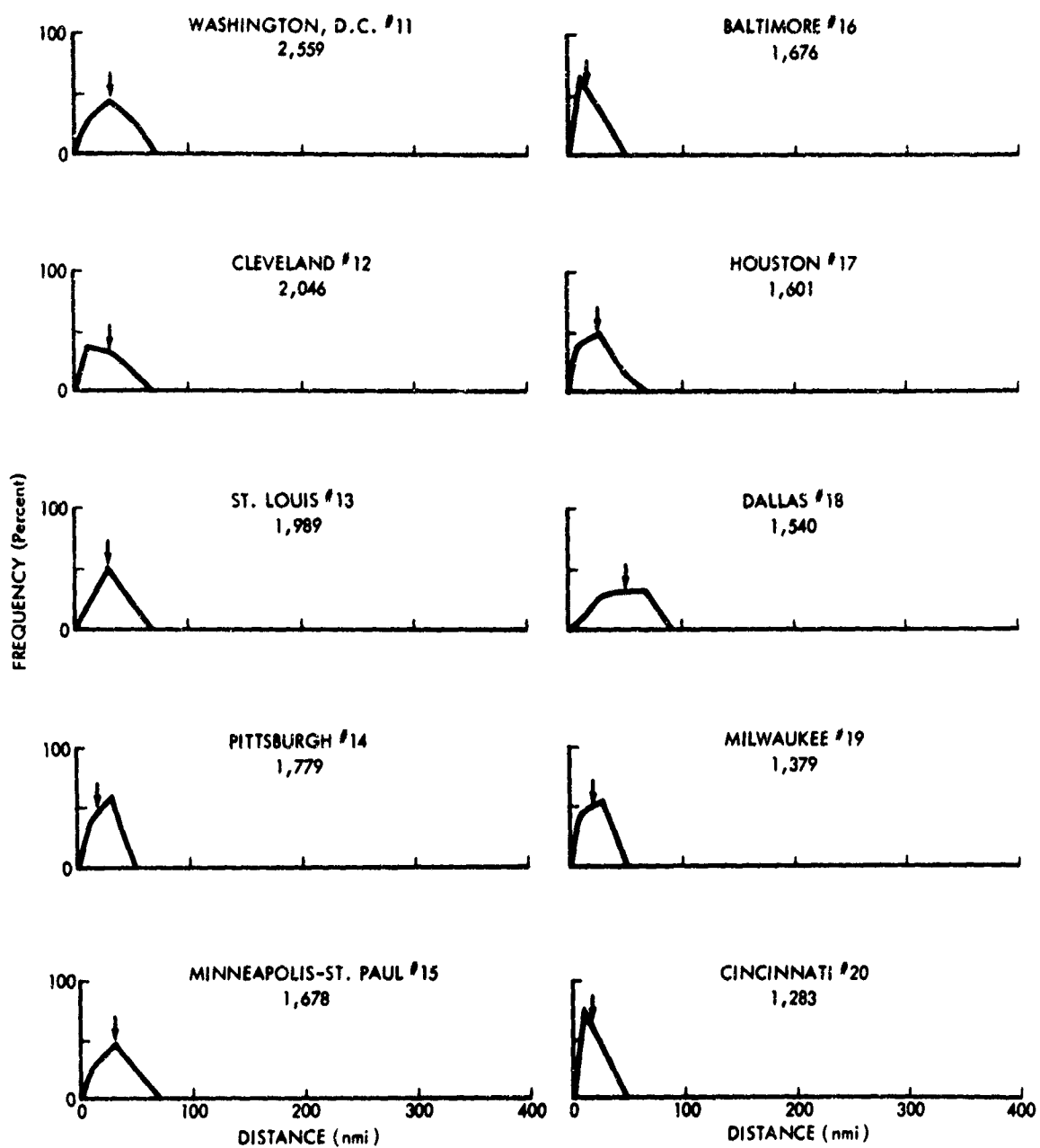
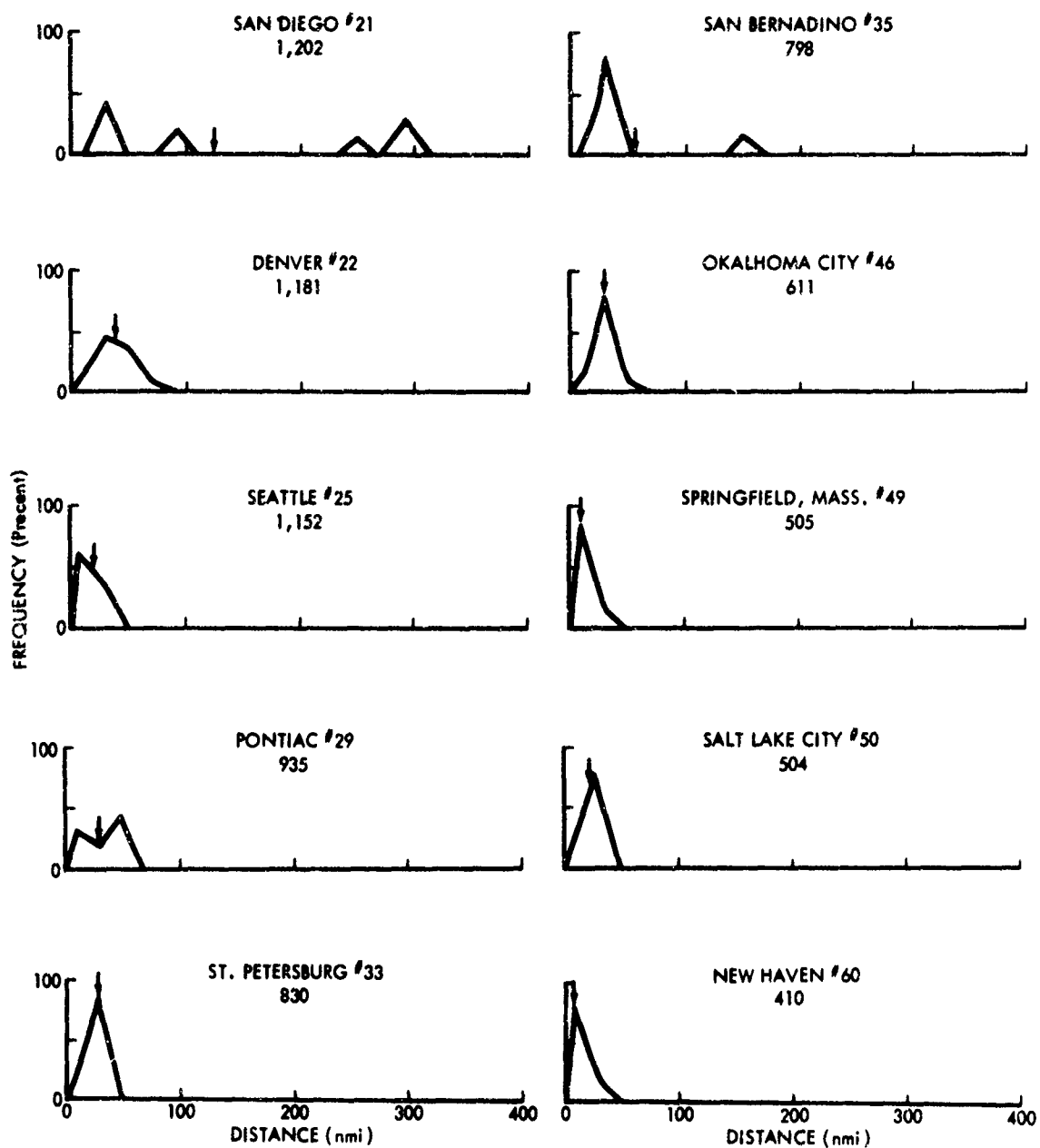
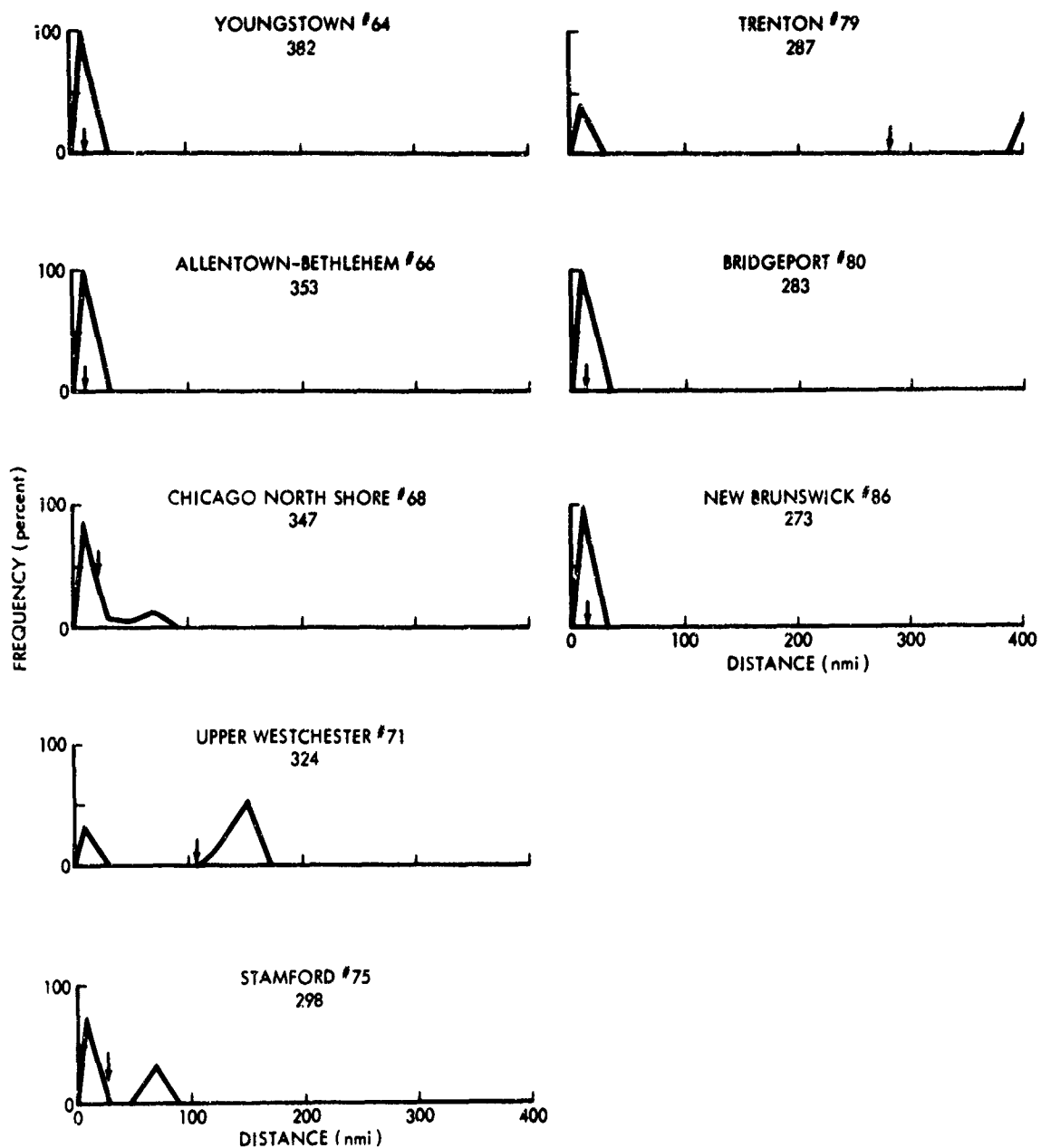


FIGURE 6. Distribution of Distance Traveled by Evacuees for Cities 11-20
in the 250,000 City Run



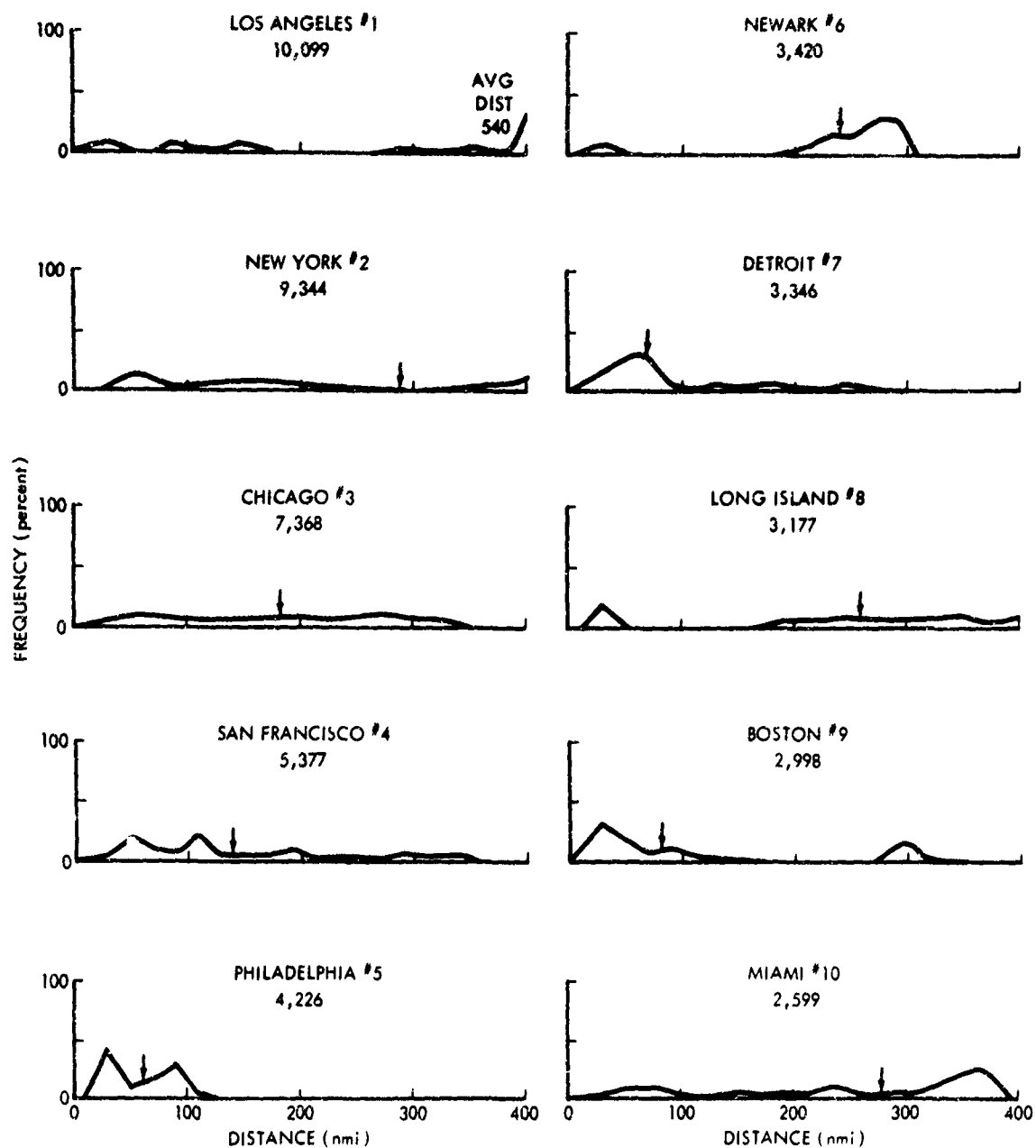
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FIGURE 7. Distribution of Distance Traveled by Evacuees for Cities 21-60 in the 250,000 Case Where the Two Runs Differ



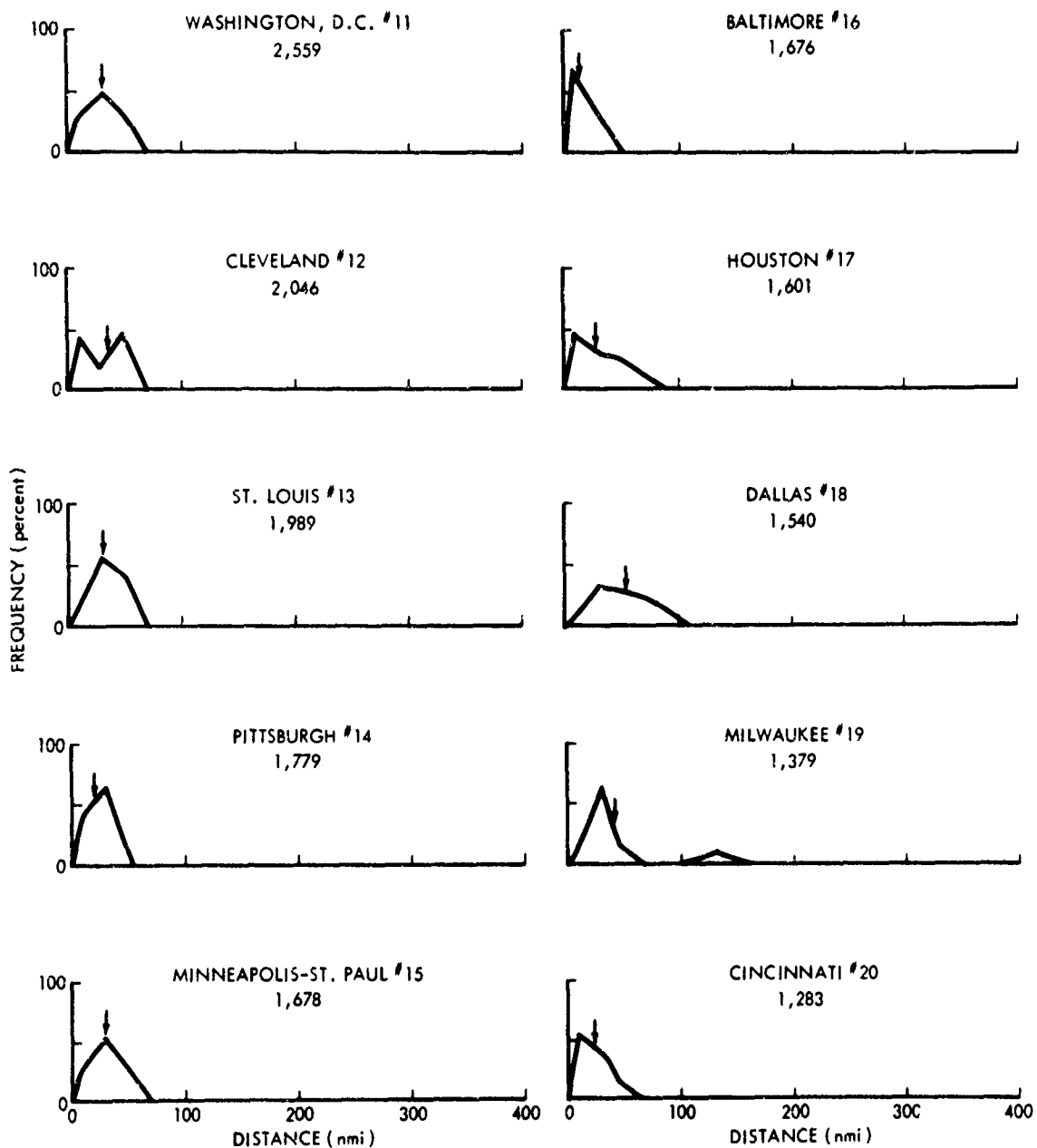
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FIGURE 8. Distribution of Distance Traveled by Evacuees for Cities 64-86
in the 250,000 Case Where the Two Runs Differ



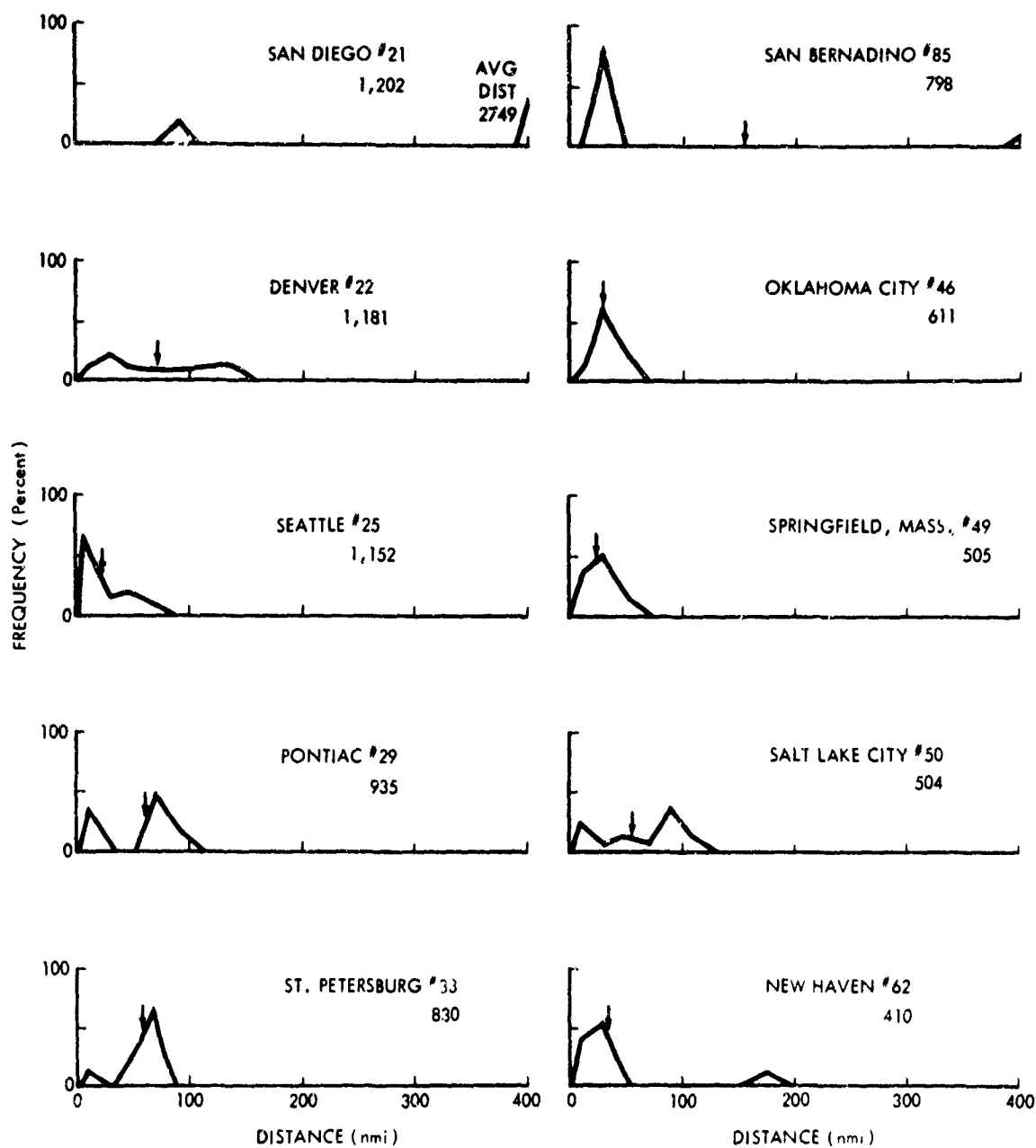
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FIGURE 9. Distribution of Distance Traveled by Evacuees for Target 10 Cities in the 50,000 City Run



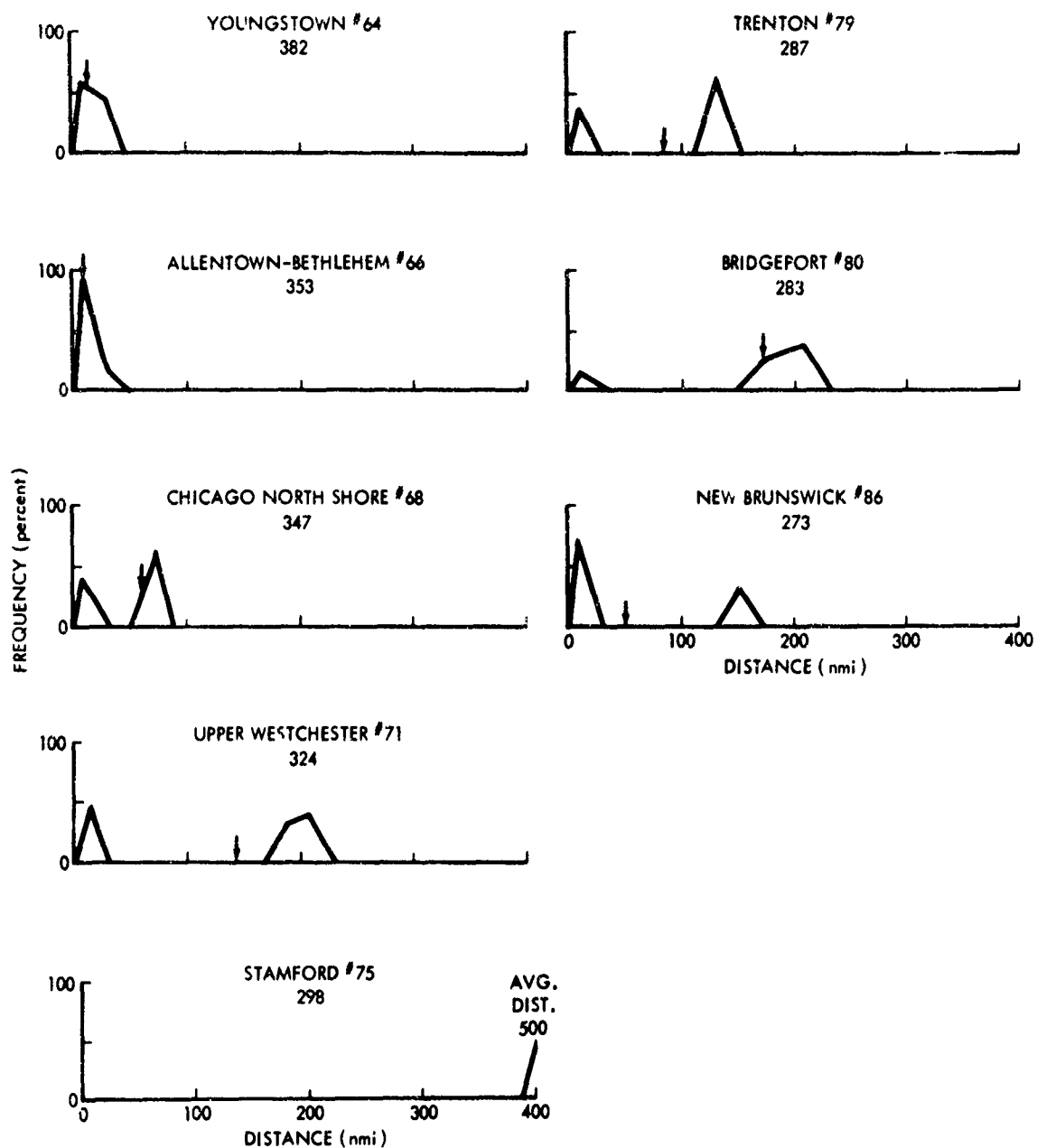
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FIGURE 10. Distribution of Distance Traveled by Evacuees for Cities 11-20
in the 50,000 City Run



P 8-26-70-11

FIGURE 11. Distribution of Distance Traveled by Evacuees for Cities 21-60 in the 50,000 Case Where the Two Runs Differ



P8-26-70-12

FIGURE 12. Distribution of Distance Traveled by Evacuees for Cities 64-86 in the 50,000 Case Where the Two Runs Differ

IV

APPLICATION OF RESULTS TO SOUTHEAST MICHIGAN

This section presents the results for Southeast Michigan as an example of the nationwide calculation. Southeast Michigan was chosen because of the large number of civil defense studies on Detroit, and not because of any special patterns anticipated for this region. It is hoped that this discussion will indicate the direction further analysis could take in the development of a nationwide evacuation scheme.

Figures 13 and 14 illustrate the allocations obtained for the first two iterations for the 250,000 case. The allocations for the first three iterations for the 50,000 city case are illustrated in Figures 15, 16, and 17. The letter symbol in each county designate the large city from which the population is assigned. To keep the figures from being too cluttered, the allocation to the small urban centers is not shown. The allocation of small cities in a county is generally to the same large city as the allocation of the rural county population illustrated. Each figure has a table showing the city assigned to each letter, as well as the original and residual population of the cities at the end of the iteration considered, and the average travel distance of that population evacuated. If a letter symbol is circled, it indicates the reception center is filled with people from the city to which it is assigned. For each evacuated city there is usually one reception center that is partially filled, it is also circled. If a letter symbol is not circled, it indicates that the larger city did not need this reception center, and that it is available for reassignment on the next iteration. The heavy solid lines delineate the regions assigned to each of the larger cities. For the 50,000 city case, there are four counties in Ohio just to the east of Toledo that receive Detroit population and two counties that receive population from Pontiac. These are not illustrated on the figures.

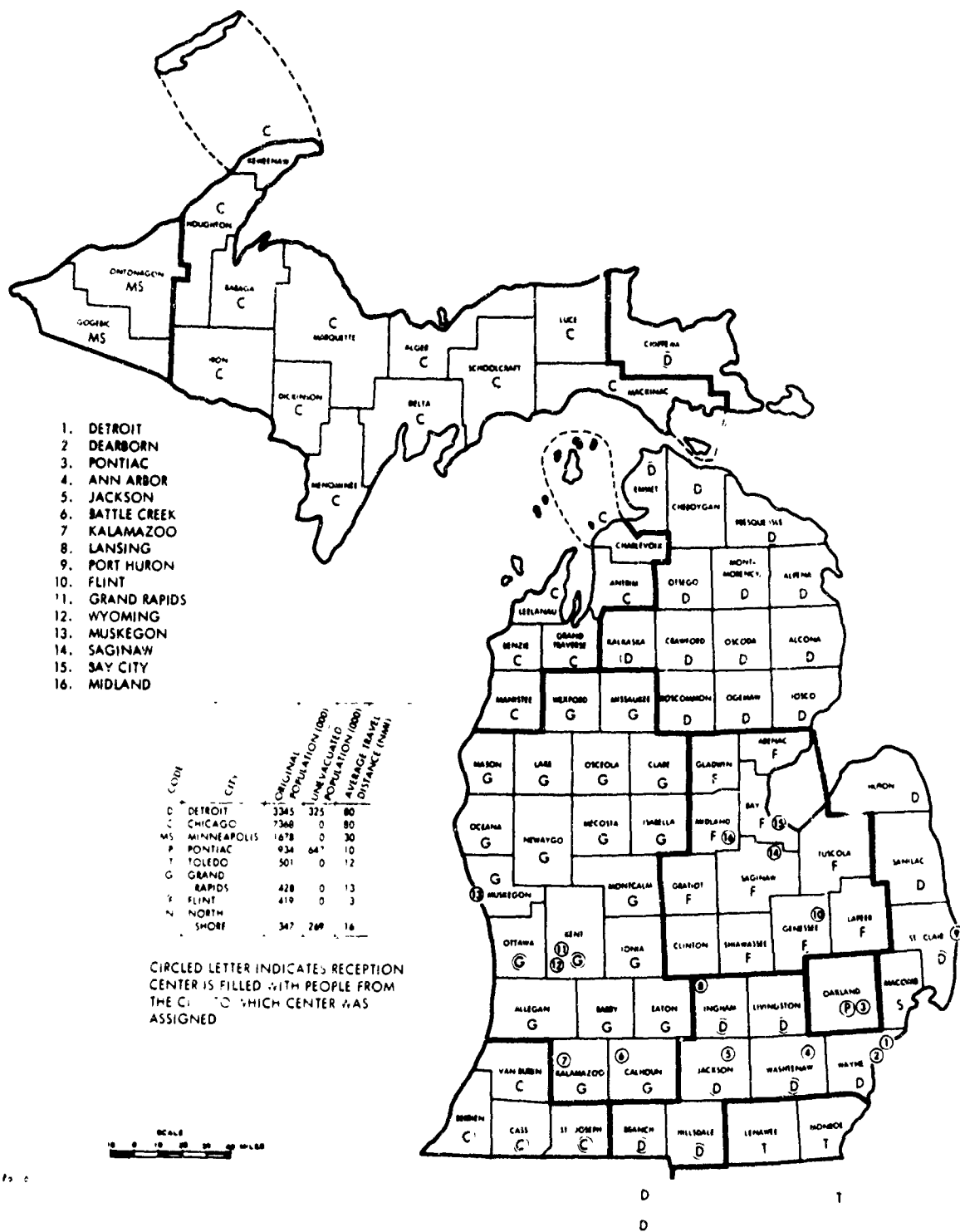


FIGURE 13. Dispersed Population--First Iteration for the 250,000 City Case

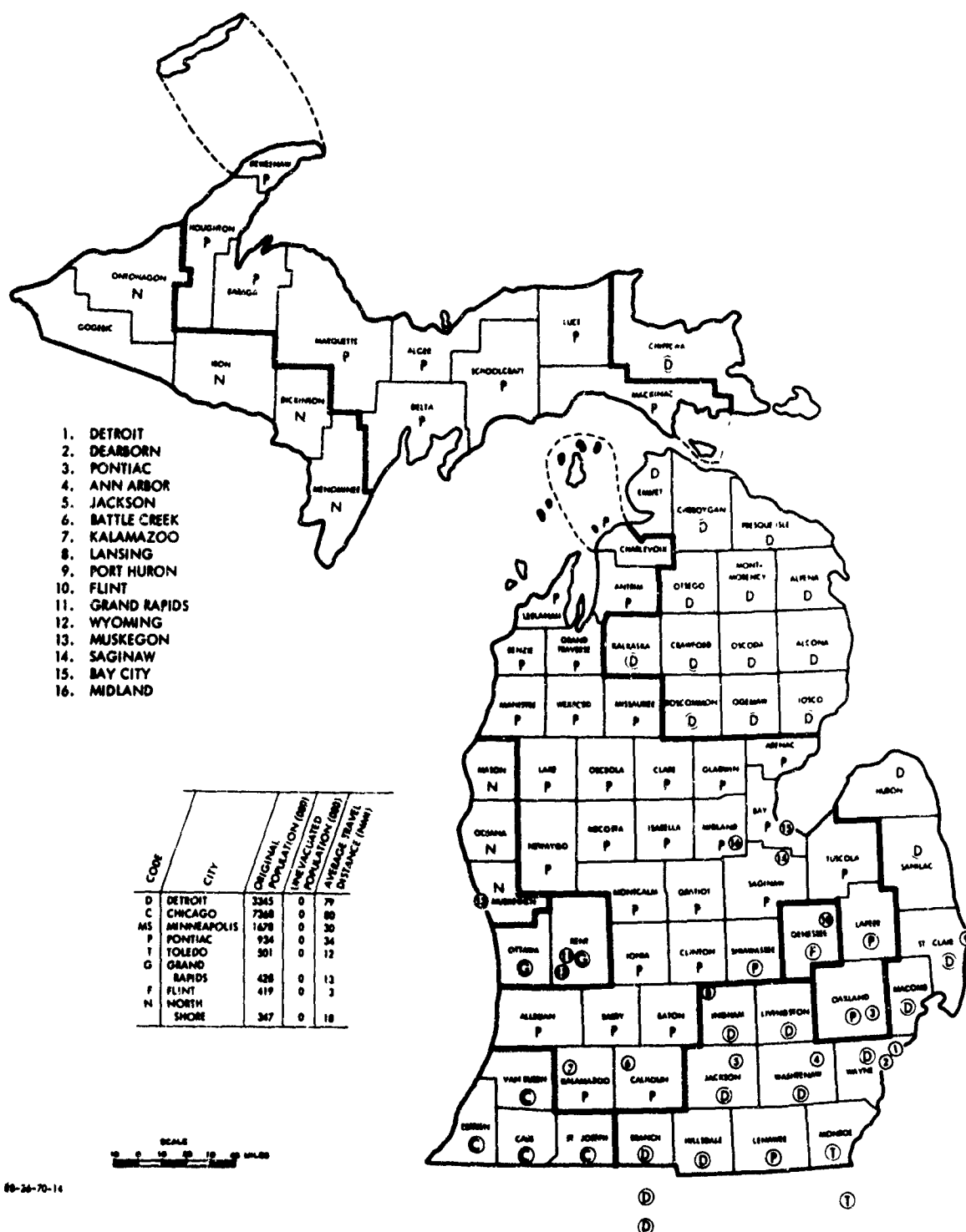


FIGURE 14. Dispersed Population--Second Iteration for the 250,000 City Case

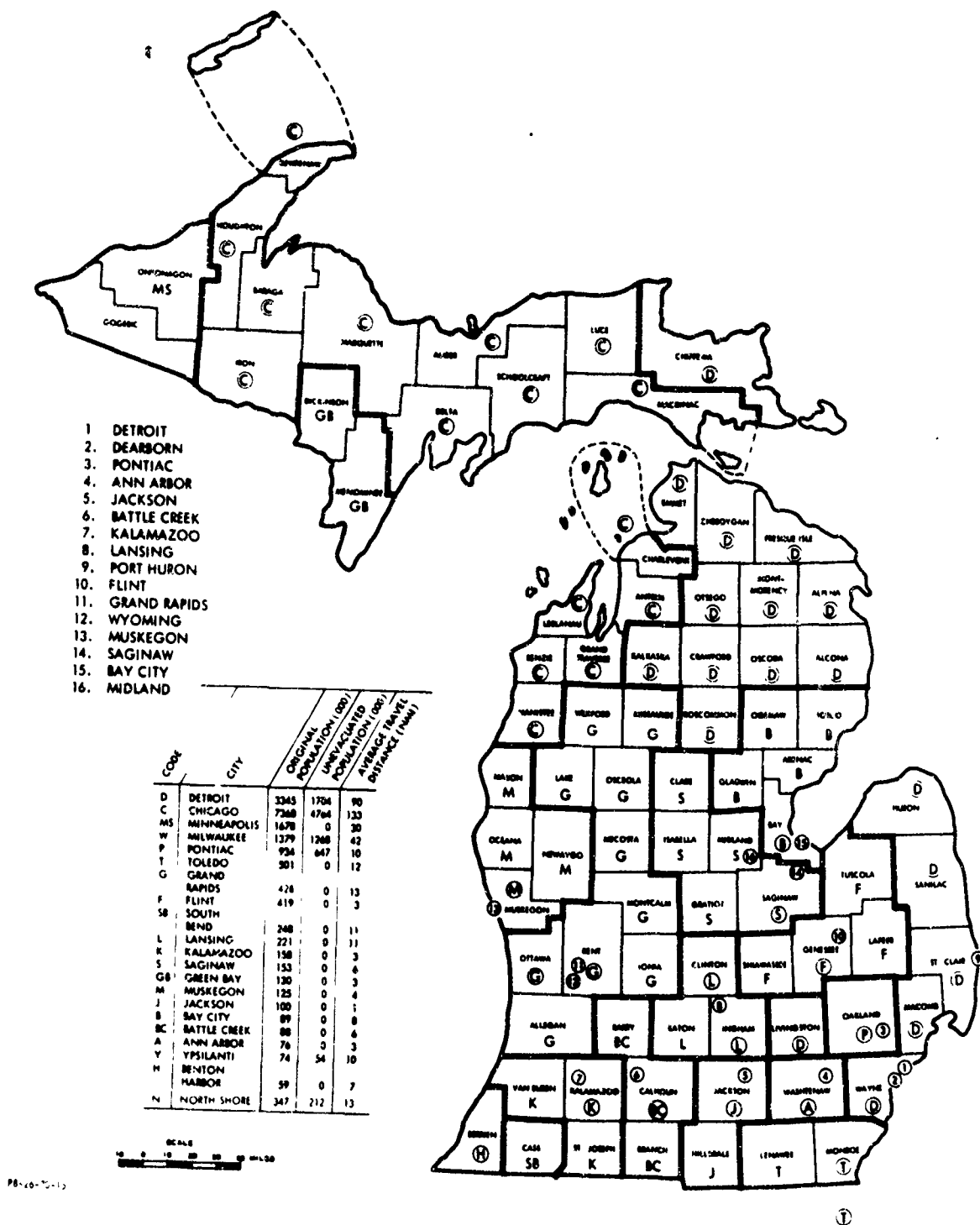


FIGURE 15. Dispersed Population--First Iteration for the 50,000 City Case

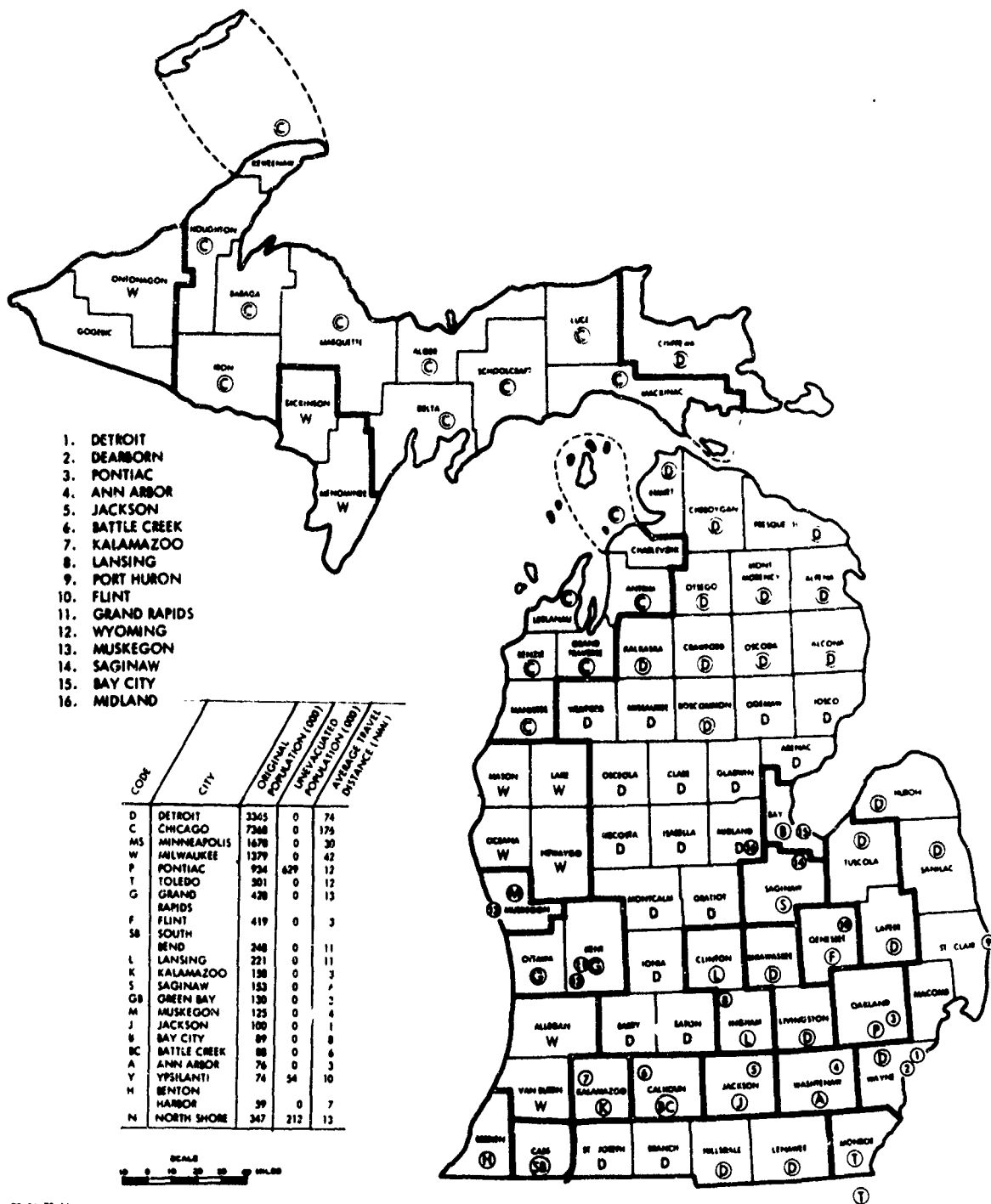


FIGURE 16. Dispersed Population--Second Iteration for the 50,000 City Case

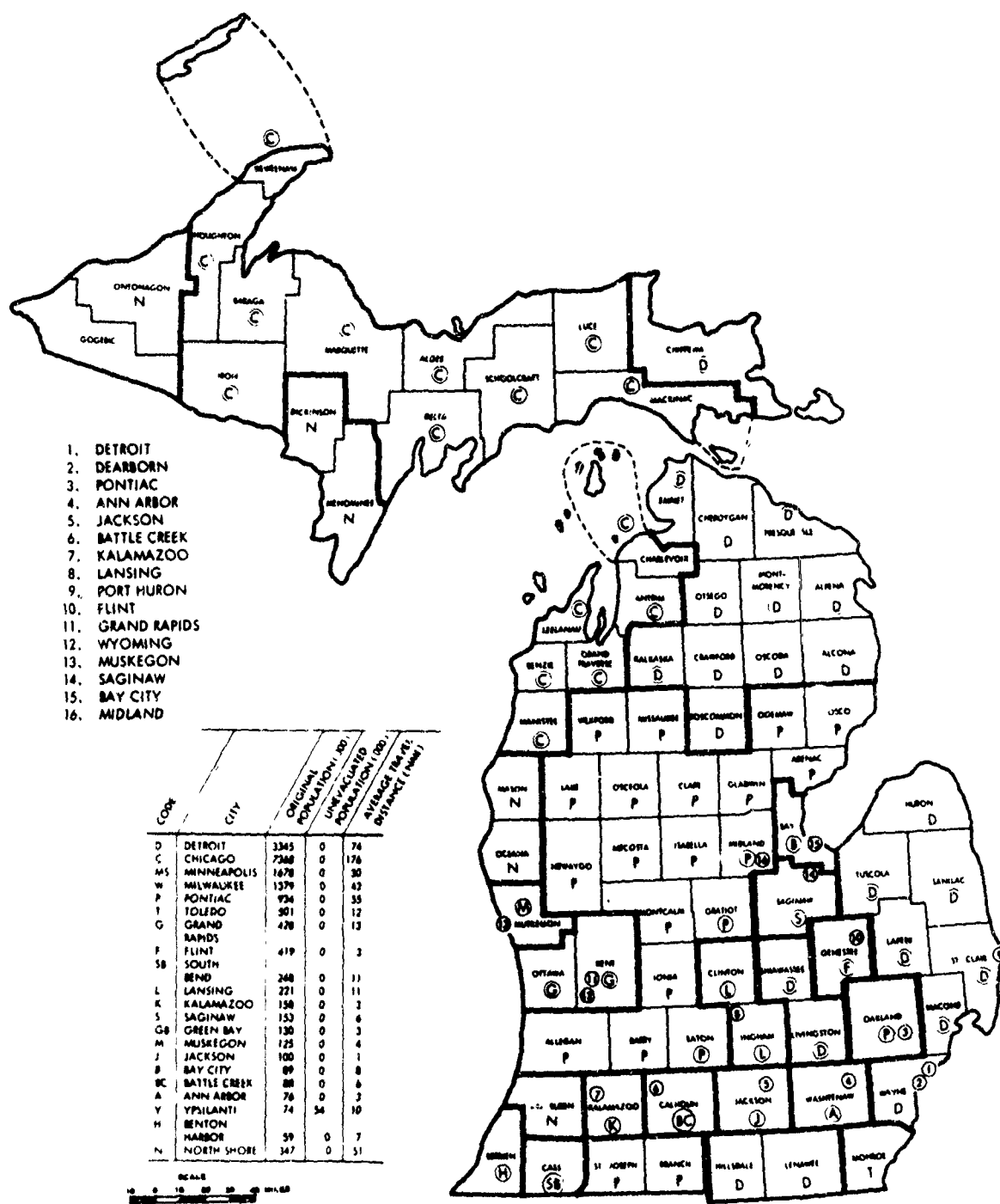


FIGURE 17. Dispersed Population--Third Iteration for the 50,000 City Case

In Figure 17, Ypsilanti is shown with 54,000 people unevacuated. This population was evacuated in the next iteration and had an average travel distance of 47 miles.

As is evident, the 50,000 case yields a larger number of different regions than the 250,000 case. Moreover, the smaller cities tend to claim the county in which they are located and possibly an adjacent one. The larger cities, such as Detroit, often have to evacuate population to counties that are not even adjacent.

One of the areas where the allocation algorithm could be improved is illustrated in Figures 13 and 14. (The same phenomena is seen in Figures 15, 16, and 17.) The first iteration allocated a band of counties across Central Michigan to Flint and Grand Rapids. These cities, however, only used three counties to receive their population. Detroit was allocated counties above this band and filled them all. On the second iteration these central counties were claimed by Pontiac which only filled a few. The remainder were left unassigned. Since these counties are left available, their reassignment would result in shorter average travel distances for the Detroit population. However, if the population evacuated to the counties in the northern part of the peninsula is reassigned to the lower part, a reduction in average travel distance of only about five miles is obtained. This is partly caused by the sparse rural population in these counties, which permits relatively few evacuees to be assigned to them.

The original availability of reception centers in the small cities is shown in Figure 18. The dot marks the city location, and the adjacent number indicates the total number of evacuees (in thousands) which could be received. If this number is limited by the evacuated population being no greater than four times the original population, the number is not underlined; if the total population reaches the 25,000 population limit, the number is underlined. In Michigan there are a total of 82 cities with a population of 656,000 which can receive 1,209,000 evacuees; 69 of these cities are in the lower peninsula with a population of 548,000 and can receive 1,046,000 evacuees. Figure 19 shows a map of the population which can be received in the

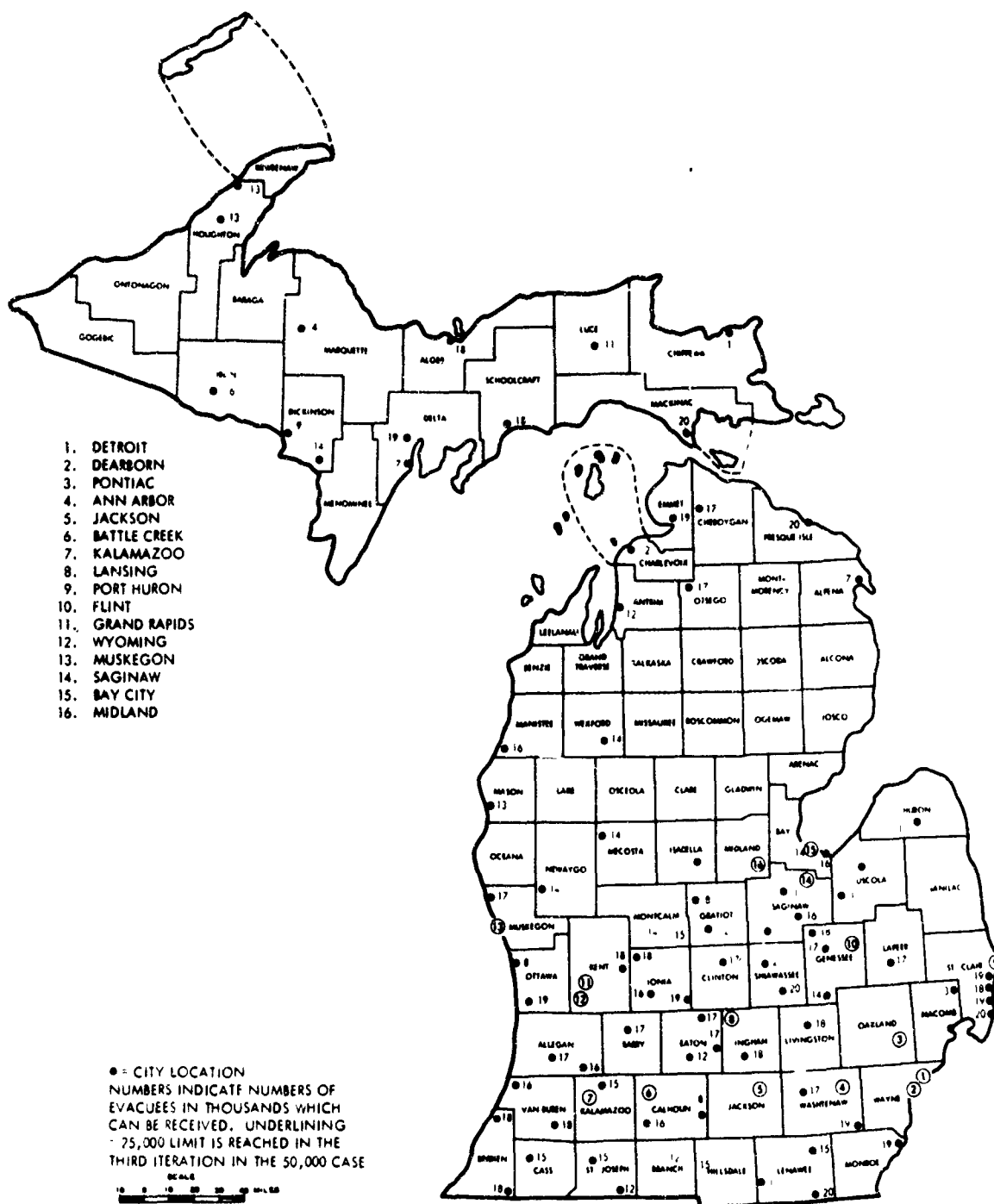


FIGURE 18. Small Cities Available as Reception Centers in Michigan

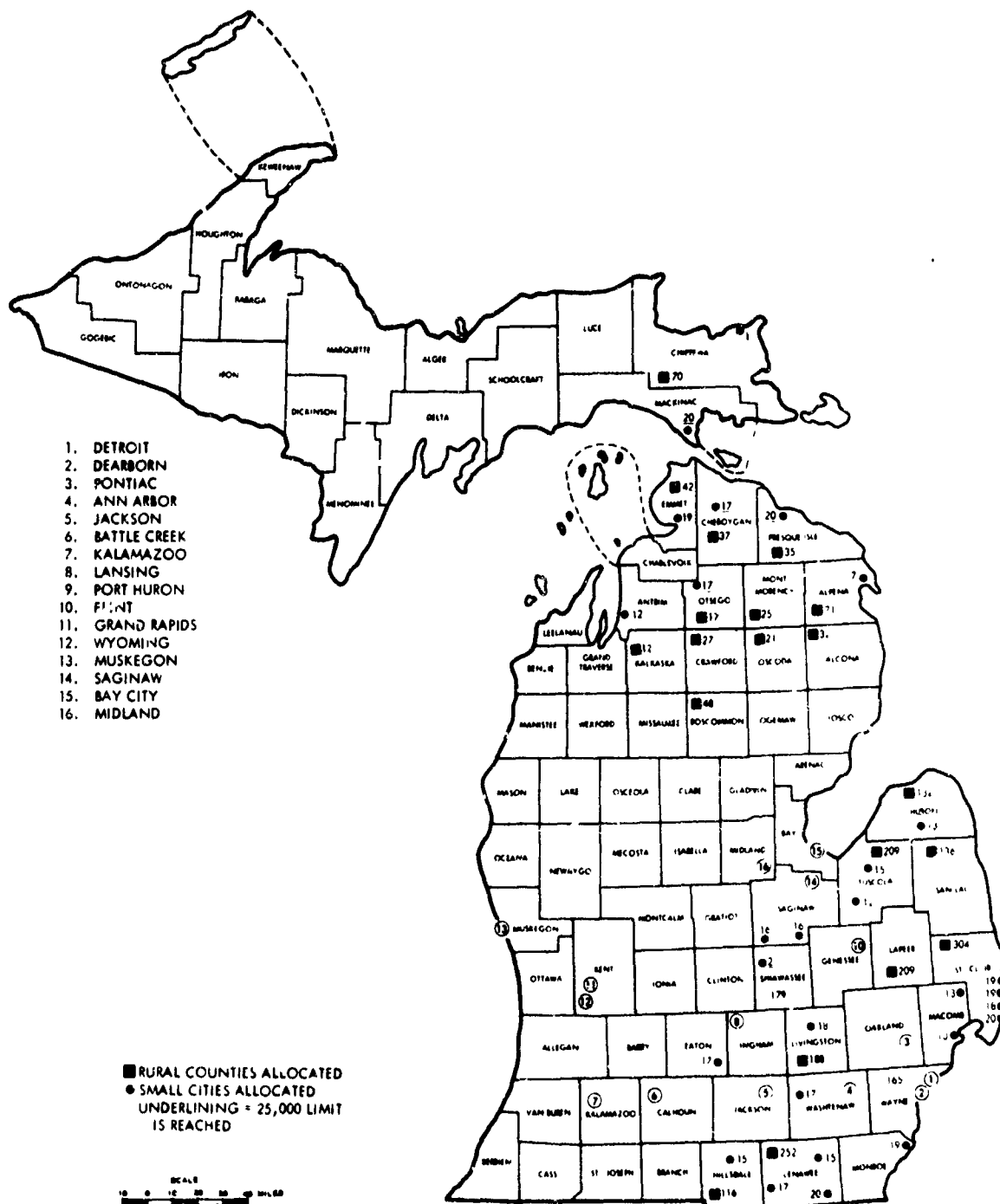
rural part of each of the counties. A total of 9,886,000 people can be received in the 88 counties of Michigan, of which 9,207,000 people can be received in the 68 counties of the lower peninsula. This gives a total reception potential for Michigan of 11,097,000 of which 10,253,000 people are in the lower peninsula. A most striking feature of these figures is the much larger reception potential, under the rules assumed, of the rural areas compared to the small cities. The ratio of these values is similar to the nationwide ratio, where the 59 million rural population can receive 236 million people, and the 20 million people in small cities can receive 24 million people. Another feature of Figure 19 is the larger rural reception potential in only the lower tiers of counties, due to the higher population density here. In fact, the lower three tiers of counties can receive 4,273,000 people.

A. 50,000 CITY SIZE AS BASE CASE

The 50,000 city case will be adopted for the rest of this section as the base case to study. In Michigan, the population to be evacuated is 6,270,000, of which 4,279,000, are in the Detroit area. Thus, if all these lower peninsula cities are to be evacuated into the lower peninsula, about 60 percent of the reception potential will be used. Seven cities--Port Huron, Midland, Niles, Monroe, Addison, Marquette, and Traverse--have a total population of 237,000; each has a population between 25,000 and 50,000 and so are not considered in this calculation.

The major area of interest is the allocation of refugees from Detroit and Pontiac, since the other cities allocate the refugees in their near vicinity. Figure 20 shows a map of the allocation of refugees from Detroit, and Figure 21 from Pontiac. These figures show both the small cities and counties serving as reception centers. The combined allocations are shown by county in Figure 22. Moreover, the allocations are divided into six regions, with the total population received in each region summarized.

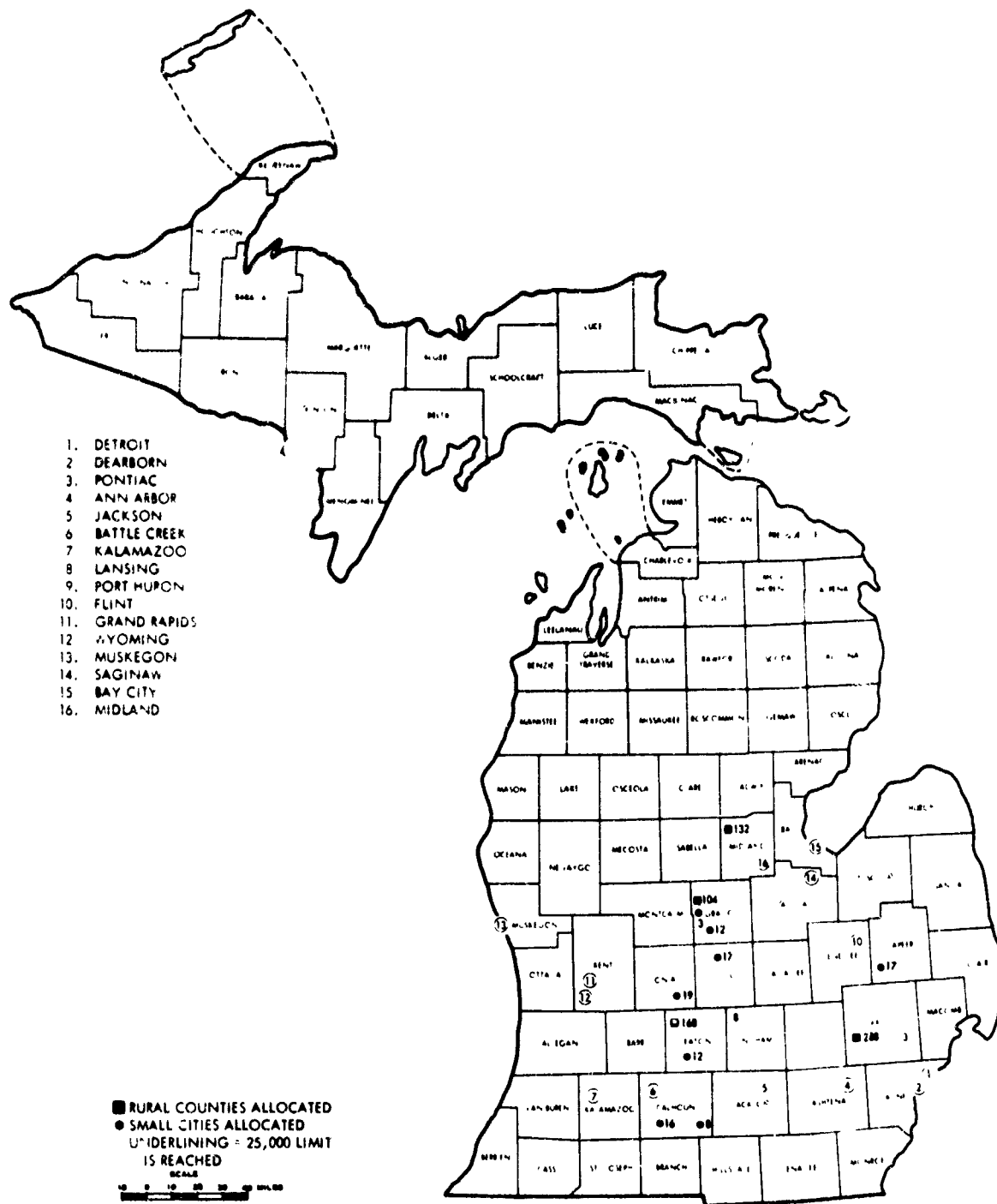
The estimated highway capacities are shown in Figure 23. The major routes are indicated with dashed lines. The highway capacity was estimated from a simple counting of two-lane roads and of lanes for



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IN OHIO
7 CITIES
87,000
4 COUNTIES
529,000

FIGURE 20. Computer Allocation of Evacuees from Detroit (Population in Thousands)



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IN OHIO
1 CITY
17,000
2 COUNTIES
160,000

FIGURE 21. Computer Allocation of Evacuees from Pontiac (Population in Thousands)

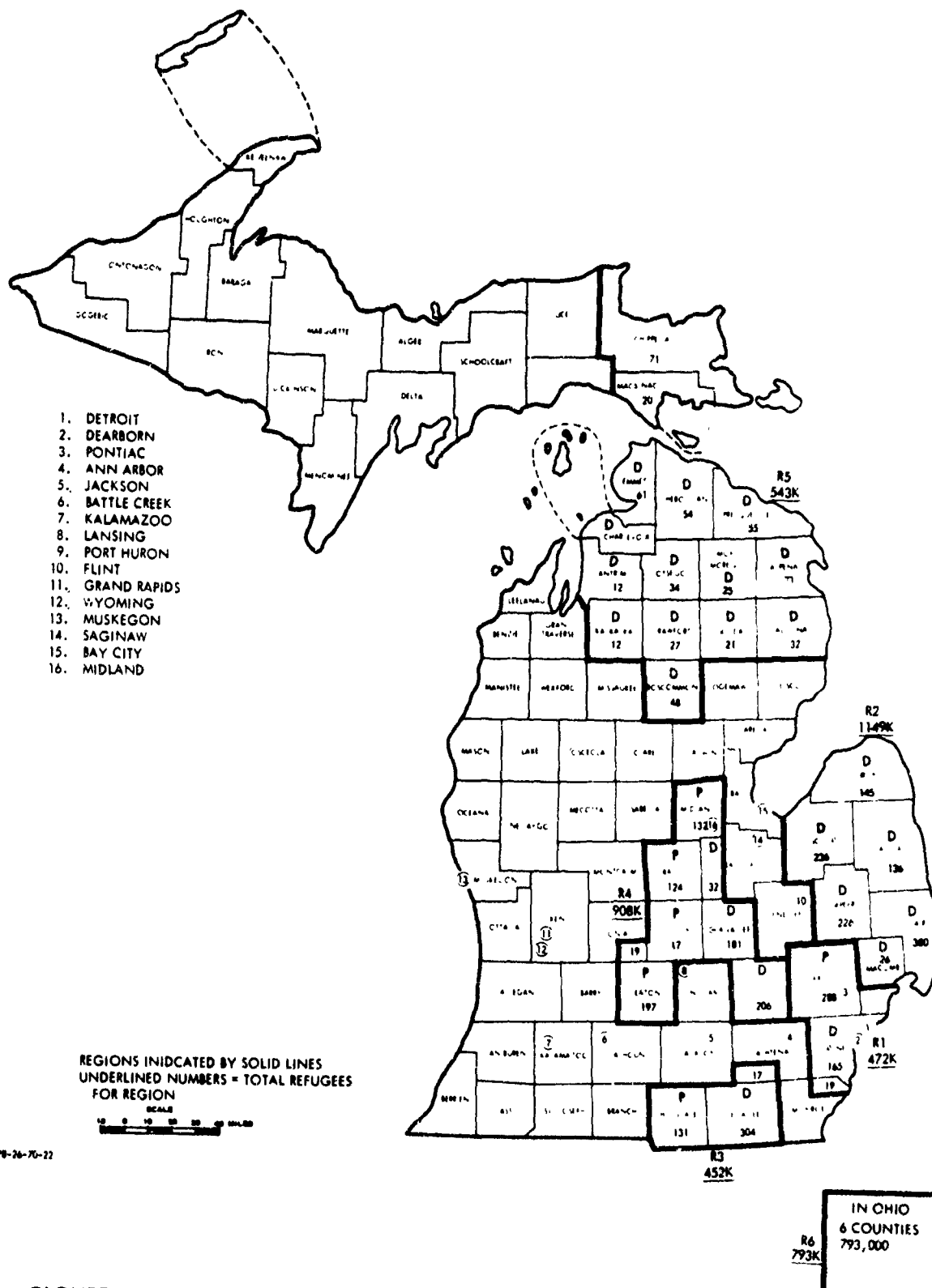


FIGURE 22. Computer Allocation of Evacuees from Detroit and Pontiac Combined
(Population in Thousands)

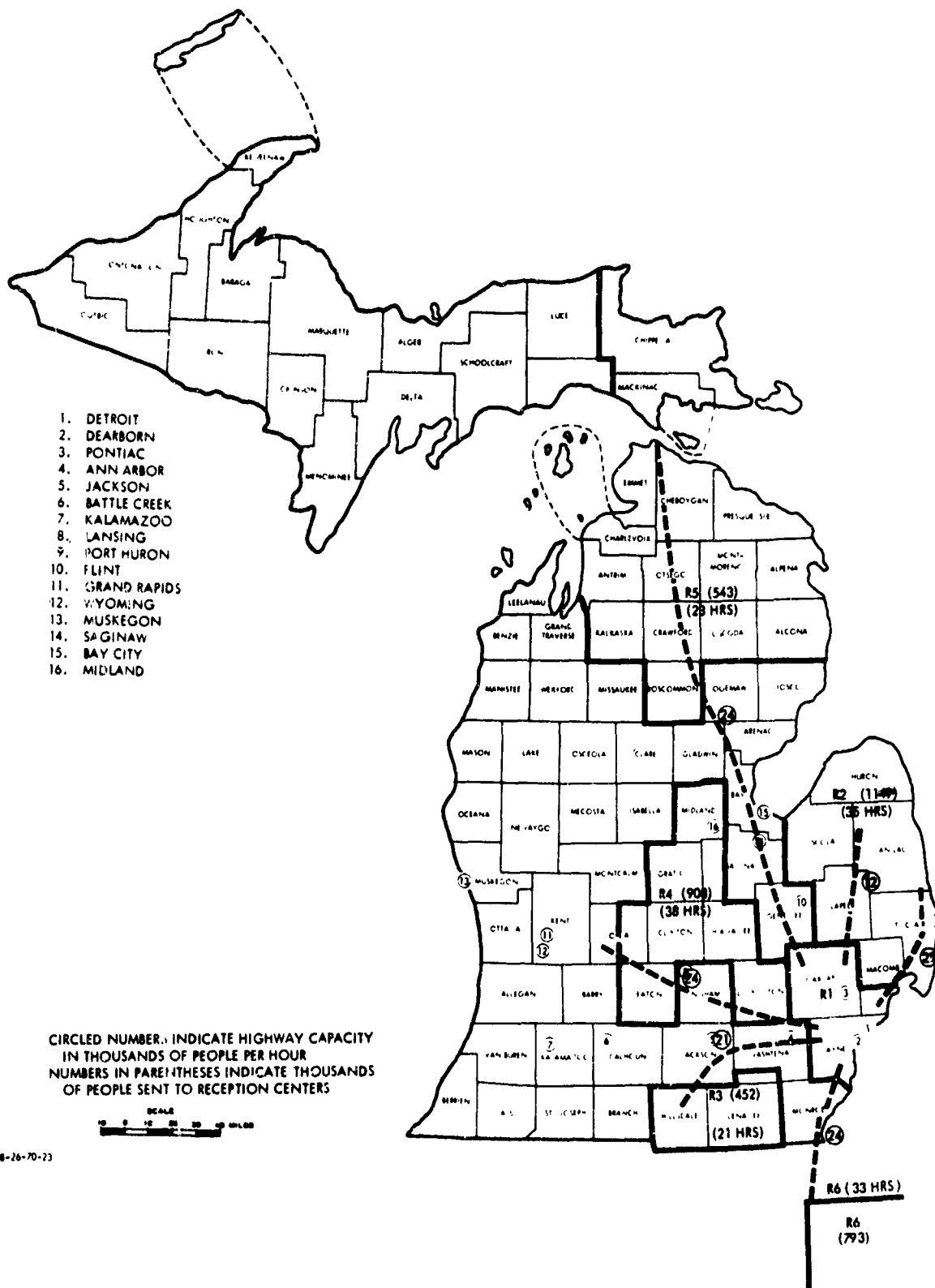


FIGURE 23. Estimated Highway Capacities and Travel Times to the Reception Areas

multilane highways to the reception centers, assuming all traffic is outbound. The number of cars per hour was taken as 1000, on two-lane roads and 1,000 per lane on three-lane or greater roads. An average of three people per car was assumed. The numbers in parentheses in each region indicate the people (in thousands) who would be evacuated to each region. The time (in hours) needed to evacuate all assignees to these regions is also shown in parentheses. The times range from a minimum of 21 hours to a maximum of 38 hours.

Not mentioned in these calculations is the possible use of rail transportation. There are adequate railway connections to each of these regions which could assist in the transportation load.¹ Of course, the time required depends upon the logistic effort and organization to support such mass movements. More precise estimates of minimum evacuation times are probably fruitless without the logistics and organization being specified.

A careful study of the computer allocation reveals areas where improvement might be made. One such improvement attempted was to allow Toledo to evacuate eastward into Ohio, releasing this territory to Toledo and giving Monroe County to Detroit. Another improvement attempted was to eliminate Region 5 which is in the northern part of the lower peninsula and therefore has a longer travel distance. However, this region may be desirable because of interstate highway and the relatively smaller amount of fallout that may cover it. The changes are listed in Table 5. Figure 24 shows the resulting allocation to Detroit in the first four regions. This reduces to slightly less than 100 miles the maximum distance which must be traveled after leaving the three central counties of Region 1. Region 5 and 6 in the figures are alternates that give an excess capacity of reception areas. These areas indicate that some alternate capability can be retained in possible plans.

1. There are approximately 30,000 railroad cars in the Detroit area which could carry people. If 100 people could be carried by each car, the 30,000 cars could carry 3,000,000 people.

Table 5
CHANGES IN COMPUTER ALLOCATIONS TO
DETROIT AND PONTIAC

County	Original Reception Potential (10 ⁶)	New Reception Potential (10 ⁶)	Reason For Change
Macomb	26	191	Basic data error gave incorrect county location.
Monroe	19	405	Switch with Toledo.
Ohio counties of Ottawa, Wood, Sandusky, Erie and Huron	579	0	Switch with Toledo.
Washtenaw	0	54	Unused potential added.
Williams, Ohio	0	74	Switch with Ypsilanti.
Defiance, Ohio	0	80	Previously un- allocated.
Branch	0	161	Previously allocated to Stamford, Conn.
Saginaw	32	218	Unused potential added.
Clinton	17	128	Unused potential added.

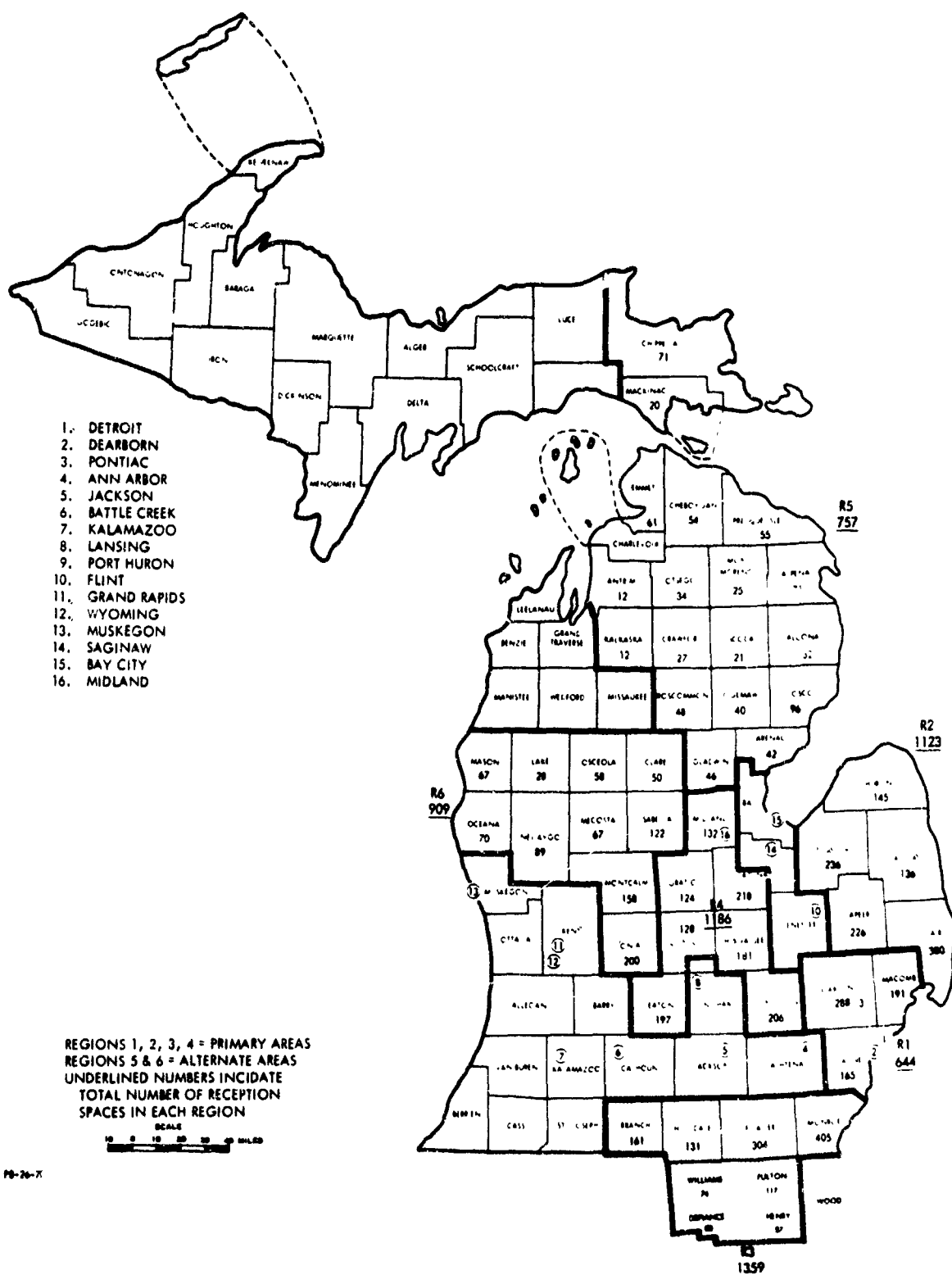


FIGURE 24. Revised Allocation of Reception Spaces to Detroit and Pontiac
(Numbers in Thousands)

B. SECONDARY ROAD NETWORK

The travel times to these six regions will be discussed now in slightly different terms which lead to more optimistic values. The secondary road network in the central region, Region 1, is quite extensive. Travel times to the boundaries of these regions can be assumed to be not greatly more than those for daily commuting. That is, travel times in the order of two or three hours might be needed to traverse these regions. The boundary between Regions 1 and 2 has a large number of secondary roads, mostly along section lines which could take considerable volume into Lapeer and St. Clair counties. There are no significant natural features which restrict the traffic flow. The prime restriction appears to be in the upper counties, where about five two-lane roads are needed to support the traffic. Here the travel time would be about thirty hours unless other roads or travel means are employed.

The travel into Region 3 can be directed over eight lanes of highway from Detroit to Toledo, and eight lanes from Detroit to Ann Arbor and Jackson. This latter route runs north of Region 3, but an extensive network of secondary roads is available. These main roads would require about 25 hours travel time unless the two close counties in Region 3, Monroe and Lenawee, were filled by the secondary roads; that case would then require only 15 hours over the main road network. Access to Region 4 is by eight lanes running to Lansing, and eight running to Flint, branching into the Saginaw or Shiawassee counties. Here about 20 hours travel times are needed unless again secondary roads can take a considerable part of the travel.

One reason for describing the travel routes in some detail is to introduce some of the questions and problems which might arise in any such evacuation travel plans. One of the most difficult problems is getting the vehicles on and off the roads. It is difficult to imagine such mass movements initiated within an hour or two. If the calculated travel time were two or three hours, one might consider an attempt at such a rapid evacuation under some very imminent war scare. If the calculated travel time were several days to a week, this time might be a limitation upon the capability to perform evacuation.

As it is, times from one-half day to one and one-half days are too long to be an effective response to an hourly developing crisis and too short to be the main constraint in an evacuation for a crisis developing over days. This suggests that an excessive concentration upon simple travel routes for an evacuation may be misplaced and other requirements should also be given appropriate consideration.

Another means of describing evacuation patterns is in terms of regional requirements. To do this, a definition of areas in terms of Economic Markets developed by the Office of Business Economics (OBE) will be used. These areas divide the county into 173 areas, each of which represent, in general, a group of counties which form a coherent market area. Figure 25 shows those areas in Michigan. Each of these could represent an organizational entity for an evacuation and would control evacuation activities within its borders. The number of evacuees, reception potential and excess capacity of the four areas covering most of Michigan are shown in Table 6. The reception potential for these areas is remarkably similar. However, the large number of people requiring evacuation in the Detroit OBE Market Area forces it to export about half of its population. The other OBE areas then become receivers of this population. Since Saginaw and Lansing are the two areas adjacent to Detroit, they might each receive about 1,200,000 people, which would fill two-thirds of their excess capacity. Thus, distinct operational roles could be assigned to each of these OBE regions.

It is, of course, recognized that many functions such as housing, food, medical care, etc. would have to be performed in an evacuation, causing immense problems of logistics. (In fact, the recognition of these problems provided the motivation for the population allocation scheme in this paper. The scheme was designed to make maximum use of the available local facilities.) The regional division by OBE areas might form a basis for civil defense planning for evacuation. The evacuation patterns obtained show some similarity to OBE areas and could be brought into the OBE framework by assigning each of these areas mutual assistance roles.

The calculations in this paper can be viewed in another light, namely, the provision of postattack assistance to large stricken urban areas from smaller unattacked rural areas. If the per capita availability of some resource might be the same in a rural area as in a major urban area, then these calculations provide directly a measure for the assistance that might be provided. If the per capita availabilities change, then the possible assistance to be provided must be accordingly adjusted.

There is one overriding requirement for strategic evacuation that presently appears to be a major limitation. This requirement is the provision of adequate fallout protection for the evacuated population.

Figure 26 shows the number of National Fallout Shelter Survey (NFSS) fallout shelter spaces available and the total population for each county in Michigan. The fallout shelter availability is a 1968 survey, and the county population is the 1960 Census count. The majority of fallout shelter spaces are in the large cities. The rural counties usually do not have enough spaces to house their own population, much less an evacuated one. This is further illustrated by Figure 27, where fallout shelter spaces are plotted as a function of county population. Again, only in the larger cities are there adequate NFSS fallout shelters.

This possible inadequacy of rural fallout shelter spaces places a major constraint on strategic evacuation. A limit on evacuation rates is probably given by times needed to expedite shelter construction or location of home basement shelters.² If these times are greater than the scenario allows, then the choice facing future civil defense officials is difficult. The focus of evacuation planning should address this central problem of fallout protection.

2. Recent OCD surveys indicate a large number of basement shelter spaces may be available in rural areas. These spaces would tend to be available in numbers proportional to the local population. This distribution would lend support to the allocation methods used in this paper as a means of assigning population.

Table 6

EVACUATION REQUIREMENTS AND CAPABILITIES
OF OFFICE OF BUSINESS ECONOMICS MARKET AREAS IN MICHIGAN

Area Number	Area Name	Evacuation Requirements (10 ³)	Reception Potential (10 ³)	Excess Capacity (10 ³)
71	Detroit	4848	2492	-2356
72	Saginaw	242	2098	1856
73	Grand Rapids	554	2064	1510
74	Lansing	567	2335	1768

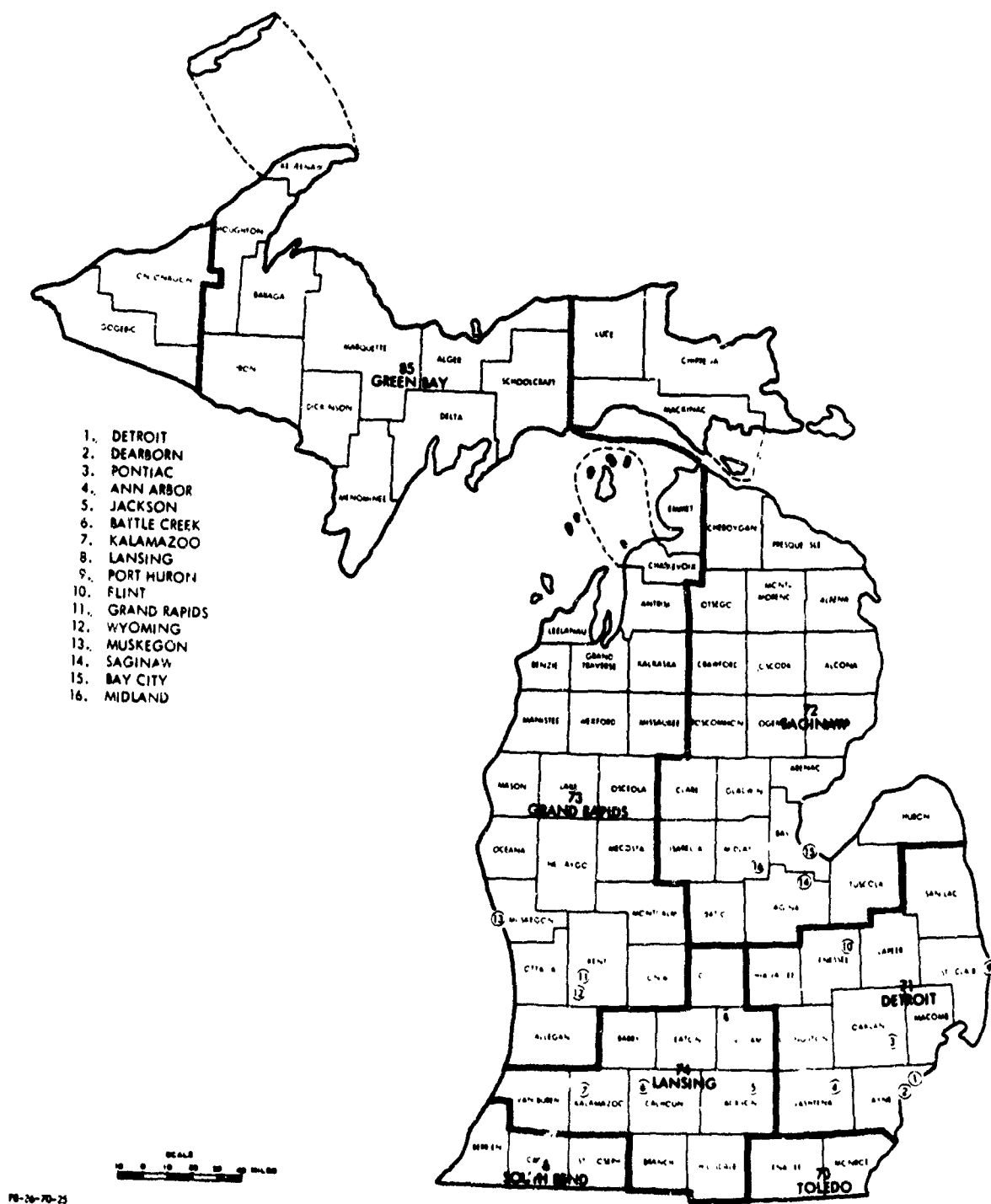


FIGURE 25. Office of Business Economics--Market Areas in Michigan

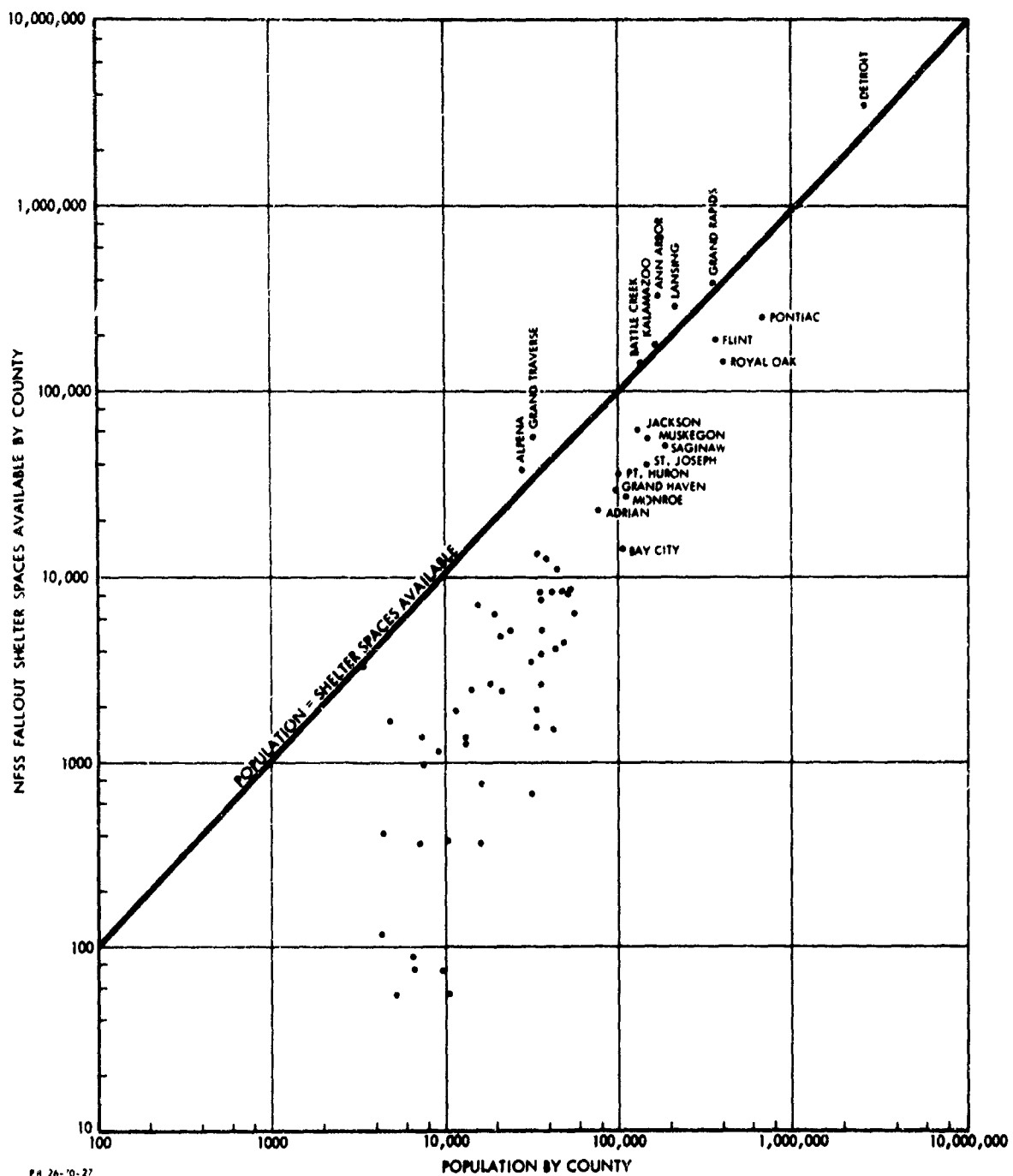


FIGURE 27. NFSS Shelter Spaces Availability by County as a Function of County Population for Lower Peninsula of Michigan

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<p>Calculations are made of the travel requirements from large urban centers to rural reception areas under the assumption that a reception area can house four times its normal population. The New York and Los Angeles areas required large travel distances; however, for the remainder of the country, average travel distances of about 60 miles are indicated.</p> <p>The computer results for evacuating the Detroit area were studied in more detail as an example of the nationwide calculations. The pattern of reception centers appeared consistent with the regional areas defined by the Office of Business Economics of the Department of Commerce. The size of these regional areas appeared appropriate as a basis for evacuation planning as well as for post-attack assistance to major centers. The most critical deficiency found, besides a lack of adequate regional planning, was a lack of fallout shelters in rural areas to house the evacuated population.</p>		

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